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Cruise Report No. 44

Glider Cruise Report No. I

Bellamite and Dynamite

15 SEP-24 NOV 2008

and

21 MAY-21 JUL 2009

RAPID glider deployment report

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ABSTRACT <p>This report describes the trial glider operations conducted as part of the RAPID-MOC project conducted between 15 September – 24 November 2008 and 21 May – 21 July 2009 between the Canary Islands and the coast of Morocco.</p> <p>The RAPID-MOC mooring array at 26.5°N is designed to quantify the strength and variability of the transport of mass and heat associated with the Atlantic meridional overturning circulation (MOC). Currently the majority of the measurements are made from moored instruments.</p> <p>The objective of this study was to assess the contribution that autonomous gliders could make to the monitoring array. In particular the focus was on the use of gliders on the shallow eastern boundary of the North Atlantic. This is the part of the RAPID array that has suffered the greatest loss of instruments, in large part due to suspected fishing activity on the continental slope. Furthermore, initial results (Chidichimo 2009) from the first three years of the RAPID array have shown that the largest contribution to the seasonal variation in the MOC is the variability of density on the eastern boundary in the upper 1000m.</p> <p>It is expected that gliders will be less susceptible to loss by fishing than the moored instruments. Another advantage of gliders is that data are retrieved in real-time via Iridium satellite communications, further reducing the risk of data loss.</p> <p>(http://www.noc.soton.ac.uk/rapidmoc and/or http://www.noc.soton.ac.uk/omf/projects/glider)</p>	
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1 Personnel

Name	Position
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Lucas Merckelbach	NOCS
Gwyn Griffiths	NOCS (NMFD)
Carlos Barrera Rodriguez	ICCM
David White	NOCS (NMFD)
Paul Wright	NOCS

Table 1.1 *Personnel involved in the RAPID glider trials*

2 Acknowledgments

We are very grateful to our partners at Instituto Canario de Ciencias Marinas (ICCM) in Gran Canaria for the use of their time and facilities, including the use of their research ships RV *Professor Ignacio Lozano*, RV *Pixape* and their RIB. We would also like to express our thanks to the ship's captain and crew. Additionally, due to the failure of the buoyancy engine in *Dynamite*, we are extremely indebted to the Search and Research team based on Gran Canaria for the glider's successful recovery and to Carlos Barrera Rodriguez for organizing it.

3 Introduction

David Smeed

The RAPID-MOC mooring array at 26.5°N is designed to quantify the strength and variability of the transport of mass and heat associated with the Atlantic meridional overturning circulation (MOC). Currently the majority of the measurements are made from moored instruments.

The objective of this study was to assess the contribution that autonomous gliders could make to the monitoring array. In particular the focus was on the use of gliders on the shallow eastern boundary of the North Atlantic. This is the part of the RAPID array that has suffered the greatest loss of instruments, in large part due to suspected fishing activity on the continental slope. Furthermore, initial results (Chidichimo 2009) from the first three years of the RAPID array have shown that the largest contribution to the seasonal variation in the MOC is the variability of density on the eastern boundary in the upper 1000m.

It is expected that gliders will be less susceptible to loss by fishing than the moored instruments. Another advantage of gliders is that data are retrieved in real-time via Iridium satellite communications, further reducing the risk of data loss.

3.1 Mission Outline

There was initially a trial deployment of one glider, *Bellamite*, from the Canary Islands. This enabled a direct comparison of data quality as compared to the present moored instruments and a consequent estimate of the MOC anomaly when using glider data compared with using data from the moored instruments. The trial also enabled us to make a detailed assessment of the practicalities and costs of working in this region.

The glider operated on the continental slope between the 1000m and 100m isobaths. Additional temperature and salinity data in this region would be particularly valuable for RAPID as the number of moored conductivity and temperature sensors has been reduced due to instrument losses in this region. The distance between the 1000m and 100m isobaths is about 25km in which a glider would make approximately 10 profiles measuring conductivity, temperature and depth with a vertical resolution of about 1m. The glider also provided measurements of the depth-integrated currents. With a glider operating at full speed ($\sim 0.45 \text{ ms}^{-1}$) this section could be repeated daily, however, a lower speed ($\sim 0.25 \text{ ms}^{-1}$) that gave greater endurance was considered to be more desirable.

The glider was deployed from a boat operating from one of the Canary Islands, Gran Canaria. During the first few days the glider remained close to the coast to ensure that it functioned correctly before transiting to the main site on the continental slope. The deployment coincided with RAPID-WATCH cruise D334 during which the moorings on the eastern boundary were serviced.

After the successful trial of *Bellamite*, another glider was purchased specifically for dedicated use on the RAPID project and named *Dynamite*. This was deployed on 21st May 2009 and after transit from Gran Canaria maintained a position on station at the EBH4 mooring site as a ‘virtual mooring’ for 45 days (Figs 6.1 and 9.1). On her return

leg the buoyancy engine failed requiring her to be rescued, which is covered in detail in sections 9 and 10.

3.2 Scientific Background and Description of the RAPID-MOC Observing System

Stuart Cunningham

The RAPID-MOC observing system has been operational since spring 2004. The project web site is <http://www.noc.soton.ac.uk/rapidmoc>. The RAPID-MOC programme has completed the initial four years of planned deployments and has now moved into a second phase (NERC Directed Programme RAPID-WATCH <http://www.noc.soton.ac.uk/rapid>) through to 2014.

The Atlantic Meridional Overturning Circulation (AMOC) at 26.5°N carries a northward heat flux of 1.3 PW. Northward of 26.5°N over the Gulf Stream and its extension much of this heat is transferred to the atmosphere and subsequently is responsible for maintaining UK climate about 5°C warmer than the zonal average at this latitude. However, previous sparse observations did not resolve the temporal variability of the AMOC and so it is unknown whether it is slowing in response to global warming as suggested by recent model results. In 2004 NERC, NSF and NOAA funded a system of observations in the Atlantic at 26.5°N to observe on a daily basis the strength and structure of the AMOC. Two papers ([*Cunningham, et al., 2007*] & [*Kanzow, et al., 2007*]) demonstrated that not only does the system of observations achieve a mass balance for the AMOC, it reveals dramatic and unexpected richness of variability. In the first year the AMOC mean strength and variability is 18.7 ± 5.6 Sv. From estimates of the degrees-of-freedom the year-long mean AMOC is defined with a resolution of around 1.5 Sv so abrupt changes would be readily identified and long-term changes will be measured relative to the 2004-2005 average.

The NERC contribution to the first four years of continuous AMOC observations was funded under the directed programme RAPID Climate Change. Following an international review of the system NERC will continue funding to 2014 under the programme RAPID-WATCH. The NSF and NOAA have also continued funding and commitments so that the system can continue operating at the same level of activity as during the period 2004-2008.

The objectives of RAPID-WATCH are: To deliver a decade-long time series of calibrated and quality-controlled measurements of the Atlantic MOC from the RAPID-WATCH arrays and; To exploit the data from the RAPID-WATCH arrays and elsewhere to determine and interpret recent changes in the Atlantic MOC, assess the risk of rapid climate change, and investigate the potential for predictions of the MOC and its impacts on climate.

3.2.1 The AMOC System

The 26.5°N Atlantic section is separated into two regions: a western boundary region, where the Gulf Stream flows through the narrow (80km), shallow (800m) Florida Straits between Florida and the Bahamas, and a transatlantic mid-ocean region, extending from the Bahamas at about 77°W to Africa at about 15°W (Figure 3.1). Variability in Gulf Stream flow is derived from cable voltage measurements across the Florida Straits, and

variability in wind-driven surface-layer Ekman transport across 26.5°N is derived from QuikSCAT satellite-based observations. To monitor the mid-ocean flow an array of moored instruments has been deployed along the 26.5°N section. The basic principle of the array is to estimate the zonally integrated geostrophic profile of northward velocity on a daily basis from time-series measurements of temperature and salinity throughout the water column at the eastern and western boundaries. Inshore of the most westerly measurement of temperature and salinity, the transports of the Antilles current and deep western boundary current are monitored by direct velocity measurements.

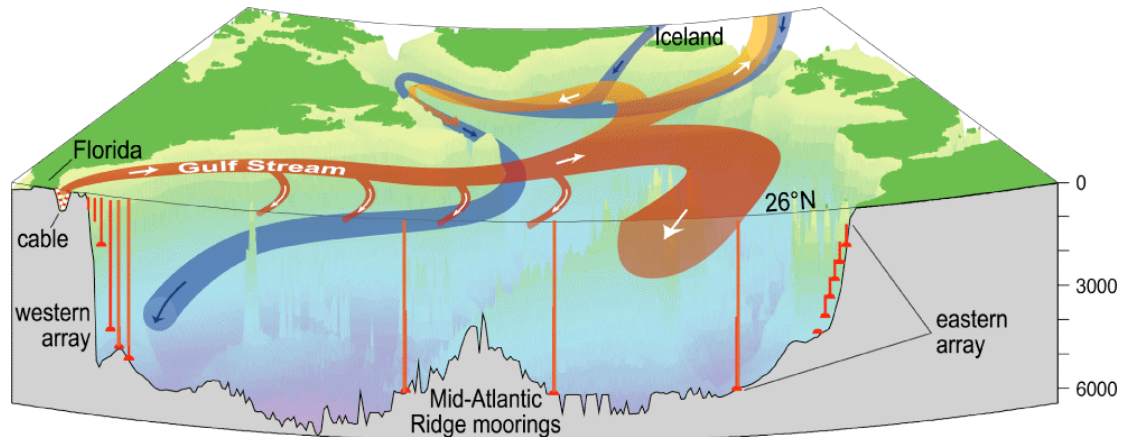


Figure 3.1 Schematic of the principal currents of the Atlantic meridional overturning circulation. The vertical red lines across the Atlantic at 26.5°N indicate the main areas where moorings instrumented to measure the vertical density profile are located. The Gulf Stream transport is measured by submarine cable and the western boundary array includes current meters to directly measure transports of the shallow and deep western boundary currents. Bottom pressure recorders are located at several sites across the Atlantic to measure depth-independent fluctuations of the basin-wide circulation. Figure courtesy of Louise Bell & Neil White, CSIRO.

3.2.2 The Eastern Boundary

The data from the RAPID array has shown that the shallow (< 500 m and often coherent to 1400 m) eastern boundary variability is important component of the seasonal variability of the MOC as a whole due to the strong seasonal wind cycle (Chidichimo 2009), which corresponds to a raising and lowering thermocline. In order to best capture the geostrophic transports it is important to monitor the potential density at the widest points of the basin at every depth. This is rather impractical and would be very expensive. Therefore, the eastern boundary array currently consists of three groups of moorings. Offshore, at the base of the continental shelf, is the tall EB1 (and until 2009 with the back-up EB2) at a depth of 5000m. Closer inshore are the shorter EBH series of moorings, with the collocated EBH4 and EBH5 being the closest inshore, and crawling up the coastal boundary are the EBM series of mini-moorings. Chidichimo demonstrated that the merging of the profiles from the three groups of moorings captures this variability well.

Due to the upwelling of nutrient rich water and the close proximity to Africa and the Canary Islands this area is heavily fished, resulting in a higher risk of mooring loss for the shallower moorings, with a total of eight moorings lost to date. The moorings were designed with an overlapping depth range to act as a back up for each other if required. However, Chidichimo (2009) concluded that there are considerable differences between the transport estimates based on the overlapping profiles produced by EB1 and EBH

and therefore EB1 could not be reliably used as a back-up for the inshore moorings as it is located too far offshore to detect ‘potential boundary waves and /or wind-induced processes near the coast (such as upwelling or Ekman pumping)’.

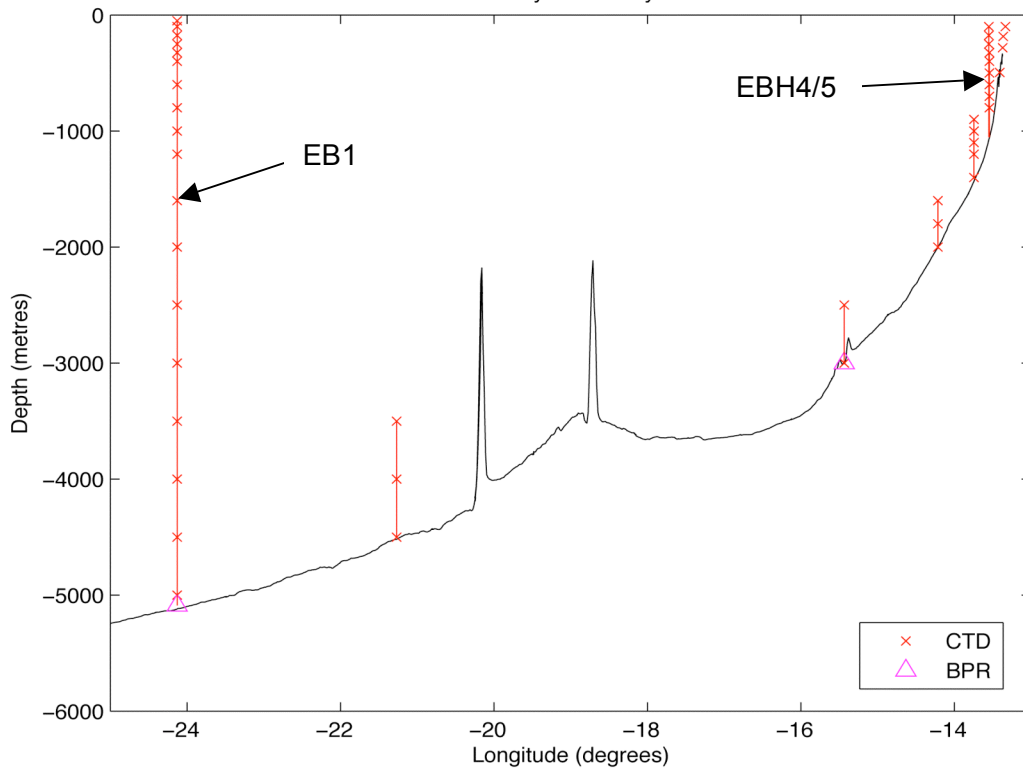


Figure 3.2 Schematic of the eastern boundary sub-array as deployed on RRS Discovery cruise D334, October 2008.

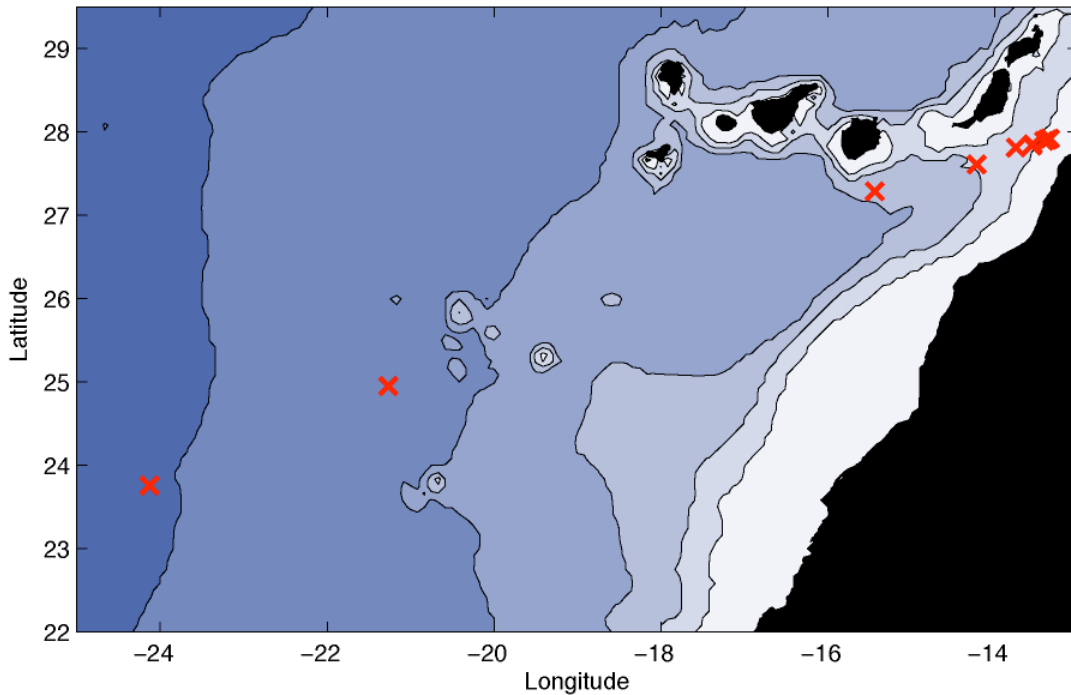


Figure 3.3 Chart showing the locations of the moorings of the eastern boundary sub-array as deployed on RRS Discovery cruise D334, October 2008.

4 Logistics

David Smeed

4.1 Diplomatic Clearance

This was the first time that the NOCS has sought Diplomatic Clearance for a glider deployment. Previous deployments had been from vessels and with partners from the country with jurisdiction over the waters where the experiments took place. Autonomous vehicles were not considered when procedures for making applications for Marine Scientific Research were developed and so the status of gliders in the Law of the Sea is not completely clear. Initially when we asked the UK Foreign and Commonwealth Office to seek clearance from Spain and Morocco they replied that they would not do so unless the gliders were deployed from a UK registered vessel.

However, we argued successfully that the researching State for UNCLOS Part XIII purposes is the State in which the programming takes place or from which subsequent instructions are sent, and thus the application should in fact be made by the UK. Subsequently the UK Foreign and Commonwealth Office made an application and permission was granted by Spain and Morocco. Autonomous underwater gliders were discussed at the 9th meeting of the IOC Advisory Body of Experts on the Law of the Sea in April 2009 and the UK delegation made a presentation based on our experience (Personal communication from T. Guymer).

4.2 Freight and Customs

Lithium metal primary batteries are classified as hazardous for transportation (UN3090 hazard class 9 applies to batteries themselves, when in equipment class 9 still applies but as UN3091), and it was not possible to find a freight service that would ship the glider with Lithium batteries installed. It was then necessary for the batteries to be shipped by the supplier direct to Gran Canaria and installed there. This requires that ballasting of the glider be done at Gran Canaria (this takes about 1 day).

4.3 Deployment and Recovery

Deployment and recovery were made with the cooperation of the Instituto Canario de Ciencias Marinas (ICCM) who have provided use of their facilities at no charge. However, they have requested that we collect some data close to Gran Canaria for them. ICCM have made available laboratory space including a tank suitable for ballasting (Figure 5.4) and boats for deployment and recovery. The gliders were launched from a RIB and commanded by the glider pilot onboard the RV *Pixape* via FreeWave radio. Getting a glider in and out of the water safely is easier from the RIB than from a larger vessel. However, it can be difficult for the glider pilot to use a laptop to command the glider for the pre-launch procedures and test dives working on a RIB and the larger vessel makes this work much easier. It also provides the capability to work further off-shore if necessary.

4.4 Other Details

As the deployments were carried out far from NOCS all equipment should be shipped ahead of time, typically three to four weeks as the authorities can take time to clear the equipment through customs. At present we are using Peters and May as the shipping agents.

The following equipment is required for deployments:

- Access to a test tank or pool – this can be fresh or sea water – but the density must be measured.
- Access to a small boat
- Access to a reliable internet connection
- An accurate balance that can measure up to 12 kg to 1 g accuracy or better
- Spring balances
- Lead sheet and ballast bottles,
- String, buoy and long rope
- Imperial and metric tools, plus the gliders special tools
- UK – European adapters
- Spare battery pack for FreeWave
- FreeWave set up and laptop
- Handheld GPS
- Spare O rings and grease
- Other spare parts
- Vacuum pump
- Manuals

There is, at time of writing, a complete set of spares and tools stored at ICCM in Gran Canaria.

5 Set Up and Operation of the Gliders

Paul Wright

5.1 Operating Principles

The reader is referred to the Teledyne Webb Research Glider User and Operator's Manual.

The glider is normally neutrally buoyant in its equilibrium state. By pumping oil into or out of a bladder located in the flooded nose cone the glider effectively changes volume and can become positively or negatively buoyant, mainly in the nose cone. As the glider descends or ascends the wings translate a component of this vertical motion into horizontal motion. The result is a sawtooth flight profile. The glider is steered by a rudder mounted in a tail fin. Moving the forward battery pack back and forth performs additional fine pitch control. The CTD is mounted under one of the wings. The carbon fibre hull is in three main sections containing fwd) buoyancy control pump and oil reservoir and pitch controllable battery pack, centre) the science bay and aft) the control electronics, the aft battery pack, drop weight, on/off plug and the tail fin. The tail fin not only steers the glider but also has the radio, GPS and Iridium aerial. There is an inflatable air bag in the flooded tail cone for additional surface buoyancy.

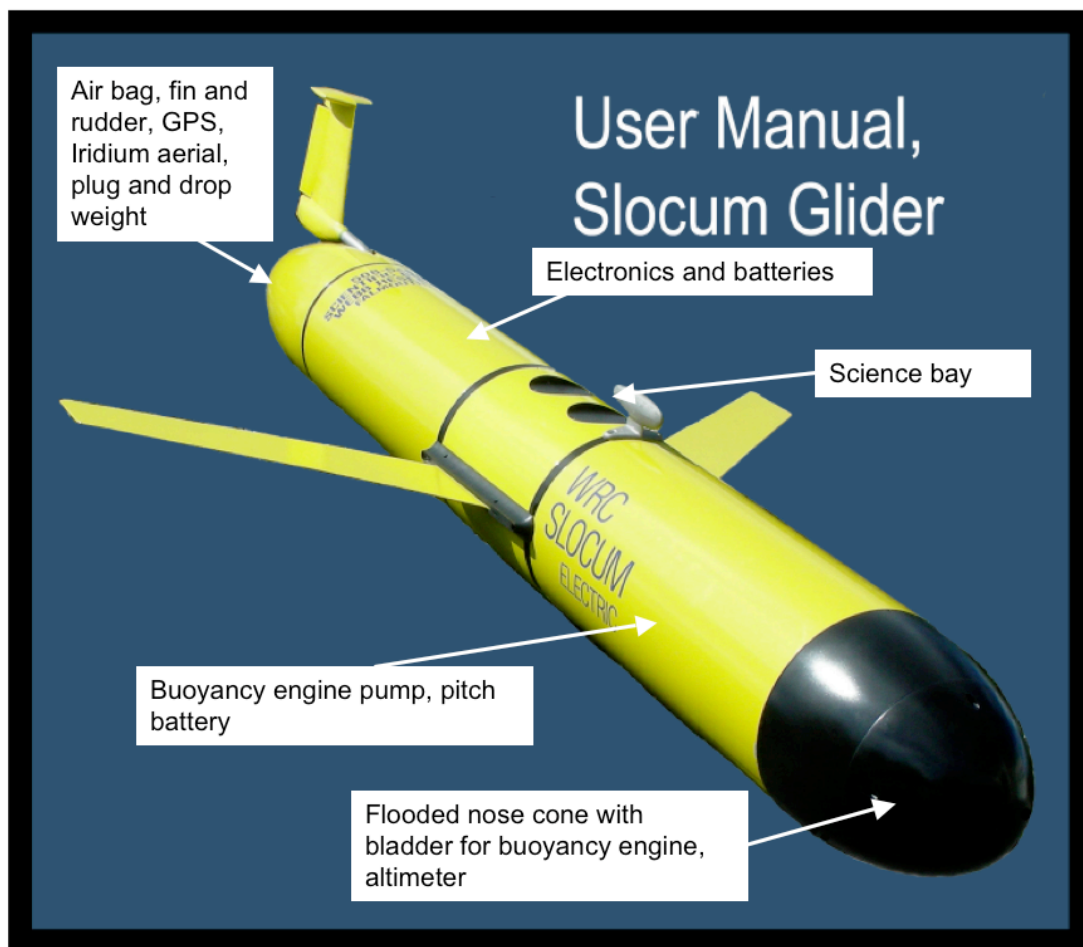


Figure 5.1 *The glider and its internal layout. (adapted from the Operator's Manual)*

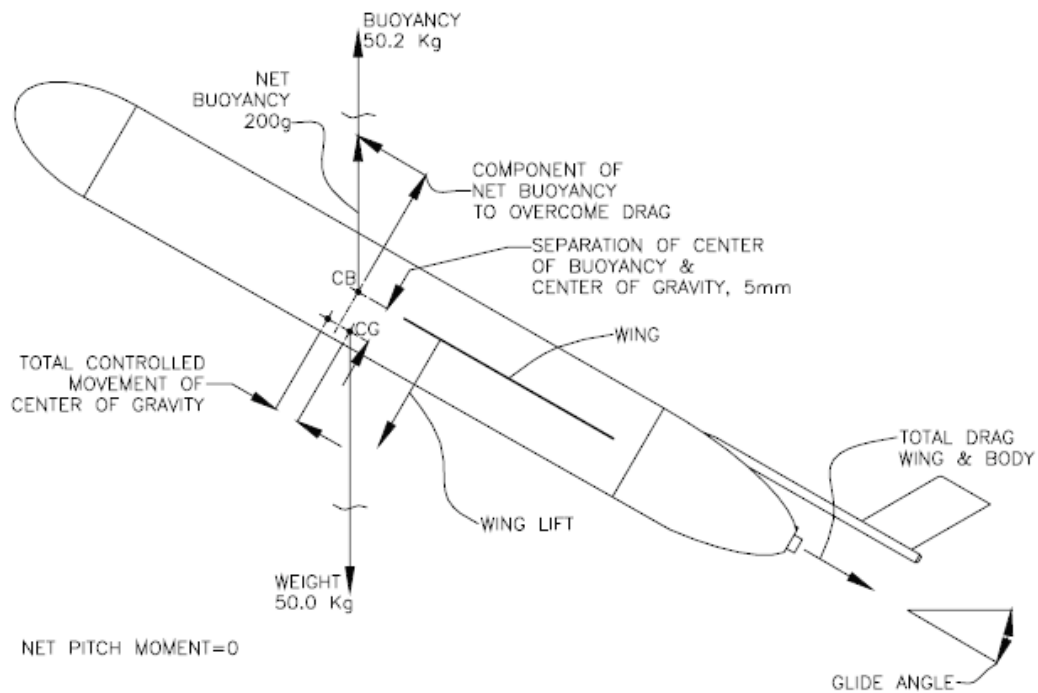


Figure 5.2 Diagram of the glider showing the forces and the centres of buoyancy and mass. (taken from *The Slocum Glider Manual*) – note: masses are approximate.

5.2 Communications

Communication with the glider can be through three basic methods:

- Iridium satellite phone to a base station in Arizona and then to the dockserver master laptop in David Smeed's office at the NOC.
- FreeWave radio, which is line-of-sight to a laptop. There is a buzzer that makes a sound when a connection is made. This is far cheaper and quicker than using Iridium. This method is usually the best for lab testing and deployment of the glider. The laptop needs to have a serial port or a USB to serial adapter and the software to drive it. Additionally minicom needs to be set up (standard on Linux machines).
- A direct serial connection from the PC to the glider.

Additionally the glider is installed with an ARGOS beacon which provides a back-up data and location facility. Usually the glider is programmed to transmit its position in the ARGOS message. Due to the fewer ARGOS satellites than Iridium there is usually a deadtime in receiving transmissions, especially at mid-latitudes, sometimes of the order of a few hours. Thus in normal operations the glider will not remain at the surface long enough for an ARGOS message to be received. However, in the event of a failure where the glider is unable to dive it could be used to locate it in the event of a failure of the Iridium or GPS units.

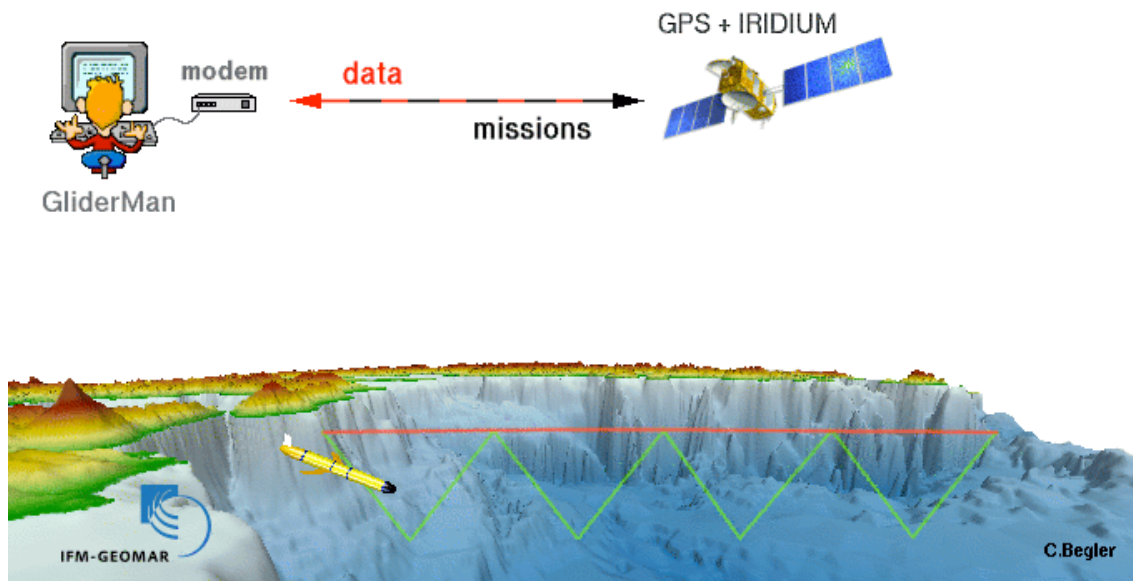


Figure 5.3 Diagram to show the basic ideas of the communication from the dockserver to the glider. (courtesy of IFM-GEOMAR)

5.2.1 FreeWave

The FreeWave radio connection is usually used in the laboratory and aboard the ship during the deployment and the early stages of the mission or recovery. FreeWave should work for Window PCs but we haven't had any success with it yet. Currently the best option is to use one of the Linux laptops supplied with the glider fleet. A good check to make is to connect to one of the NOCS fleet in Southampton prior to traveling overseas!

The FreeWave radio is connected to the serial port of the PC. For laptops without a serial port a USB to serial port adapter is required. It can be installed with a buzzer mounted inline which sounds when a connection is made. Each glider has it's own FreeWave unit, however if the serial number of the FreeWave transponder inside the glider is known, then they can be set up to connect with any of the gliders. (pg 61 of User Manual). For future reference the FreeWave serial number for *Dynamite* is 881-2570.

Linux

Connect the FreeWave box to the serial port on the laptop. If necessary use the USB adapter. Open a terminal window and type `minicom s0`. This should be responsive and give a menu of options. If the FreeWave has been set up (and they should be!) nothing further needs to be done. When the glider is powered up and transmitting the terminal window will fill with the communication from the glider. Type `^C` when requested to prevent the glider starting a mission. Then type the following:

```
put c_air_pump 0 (turns the air pump off to stop inflating the aft buoyancy)
use - iridium (or callback 30 to turn off the Iridium transmitter)
```

It is now possible to safely and cheaply communicate with the glider.

Windows

This should be similar to the above, with the difference being that you need to use 'hyperterminal' or something similar. However, we have found that once past the setup menu (see page 61 of User Manual) that the program fails when the set up menu is exited. It would be convenient if this worked better.

5.2.2 Iridium Communications

There are three methods of communicating with the glider over the Iridium network. One is by using the glider's 'dockserver' computer at NOCS, the others involve connecting to the dockserver remotely using SSH tunnels and a VNC terminal.

Dockserver

An application called 'GliderTerminal' should be open on the desktop. The application has three main windows of interest, the output pane, the command pane and the script pane. When the glider makes contact there is an audible alarm and the command window becomes active. Typing a command into the command window will produce an echo and a response on the output pane.

SSH Connection

Windows – download and install putty.exe. This can easily be found using google. The setup details: name (e.g. glider-dockserver), port = 22, host = ssh.noc.soton.ac.uk, SSH tunnels = dockserver:6564, dockserver:6564, 5901 and dockserver:5901

This gets you into the NOCS server. To get into the dockserver first login as yourself with usual username and password and then:

```
ssh localuser@dockserver
```

```
Password: ****
```

If GliderTerminal is installed on your PC then it is possible to communicate directly with the glider through that. It is also possible to use the putty terminal window to manage files stored on the dockserver.

VNC Terminal

In many respects this is similar to the SSH method but useful if GliderTerminal is not installed. Connect to the dockserver using putty.exe as above. Then open a VNC application. The host is localhost (or sometimes dockserver...) and the password ****. A window displaying the dockserver's screen will appear allowing communication with the dockserver's GliderTerminal.

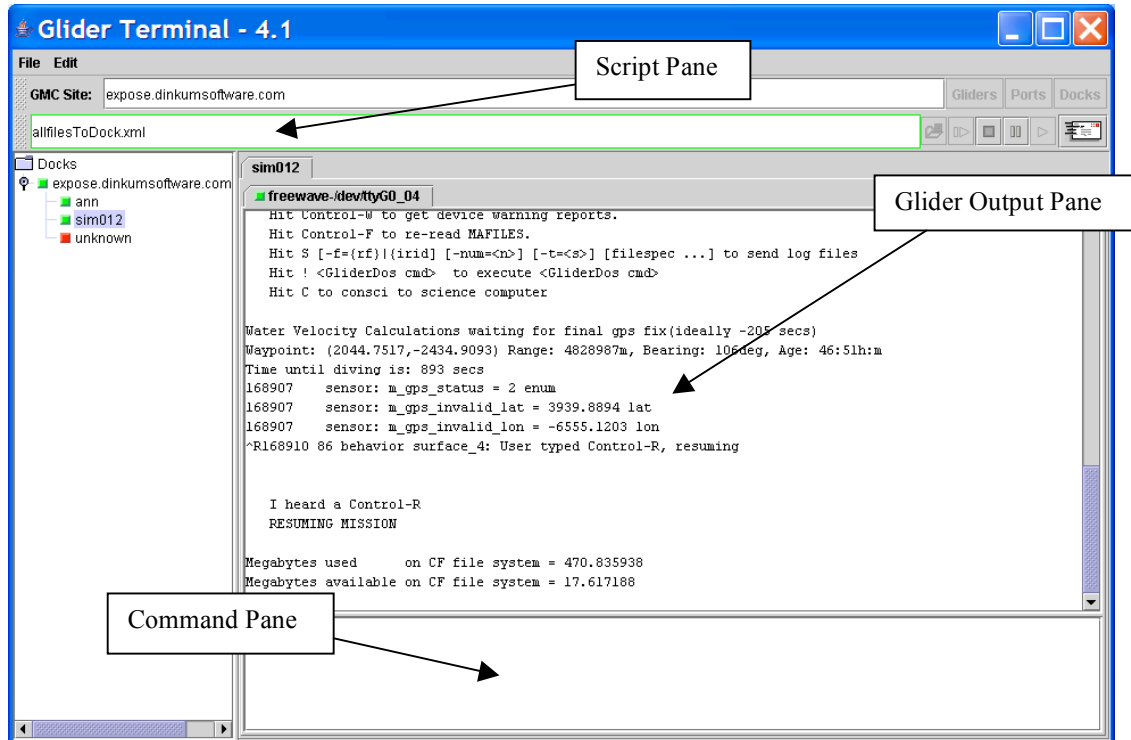


Figure 5.4 Screenshot of a GliderTerminal window. This is from the GMC Manual pg 49. The glider in this case is named “sim012”, another glider is named “ann”.

5.3 Lab-based Computer Work

When the glider is in the lab, especially if the tail cone has been removed, which is common, then it is advisable that the air pump be switched off. If the glider is in GliderLAB or PicoDOS it will not try to engage in a mission.

The normal lab mode start up routine is:

1. Switch on PC and open a terminal window.
2. Switch on the FreeWave radio
3. Type `minicom s0`
4. Power on glider using either the batteries or shore power.
5. When you are instructed to do so, type `^C` (this comes up quite fast)
6. Then disable the air pump (noisy) by put `c_air_pump 0`
7. Disable iridium by use `- iridium or callback 30`
8. Enable lab mode by `lab-mode on`, the prompt should now change to `GliderLAB>`
9. put `c_science_all 0, 2, or 4` will start the CTD. The default value of `-1` will switch it off.

There will be warnings that you are working in the lab mode.

5.3.1 System Architecture

(User Manual pages 107 – 108)

The glider runs on a two-layer system architecture. PicoDOS is the basic level framework on which the software is built. The glider missions run in the higher level operating system named GliderDOS. For convenience Webb have created another second layer called GliderLAB, which is very similar in function to GliderDOS but does not allow you to damage the buoyancy engine or attempt to run missions. NEVER try to engage GliderLAB or PicoDOS at sea!

The prompt on the display using either the terminal or GliderTerminal highlights the operating system currently running. When a mission aborts the glider leaves the mission program and drops back into GliderDOS.

PicoDOS can be useful to check whether some things are functioning correctly or to update and install new software. To start up in PicoDOS (rarely required) power up the Glider as above and type `boot pico` and then `exit reset` (or `exit pico`). You will need to proceed with steps 5 - 7 again. To return to GliderDOS type `boot app` and then `exit reset`. Or to return to GliderLAB type `boot -lab`.

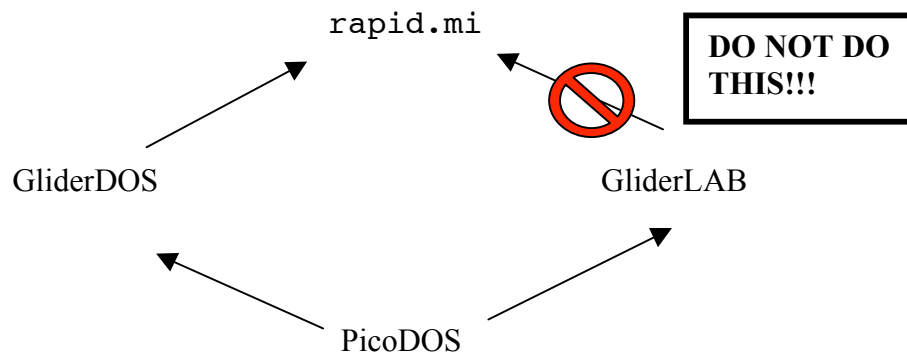


Figure 5.5 *Software architecture for the Glider*

5.3.2 Glider Directory Structure

As with Windows computers the home directory/drive of the glider is called C:\, which is subdivided into 7 directories. Directories can be changed and listed by using `cd` or `dir`.

CONFIG
BIN
LOG
MISSION
SENTLOGS
STATE
AUTOEXEC.BAT

CONFIG	
autoexec.mi	Configuration file for factory settings and calibration constants
config.sci	Specify which sensors are sent to the glider and when
sbdlist.dat	Specify which sensors are recorded on the .sbd files
mbdlist.dat	Specify which sensors are recorded on the .sbd files

simul.sim	Simulation file – DELETE for flight
zmext.dat	Automatically moves transferred files into correct directory

BIN - PicoDOS programs

LOG - mission derived data

*****.dbd	Records all sensors that are switched on
*****.sbd	Records sensors listed in the sbdlist.dat file
*****.mbd	Records sensors listed in the mbdlist.dat file
*****.mlg	Mission logs tracks calls for behaviours and devices
*****.log	Stores all the processing files.

MISSION - mission files

rapid.mi
lastgasp.mi
coptickles.mi
goto_150.ma
yo50.ma
surf50.ma
surf51.ma
abend.ma

5.4 Ballasting and Re-fuelling

(User Manual page 107 – 110)

Before the glider is deployed it must be carefully ballasted to ensure level flight and neutral buoyancy. Each battery pack has a different mass, and the lithium batteries are much lighter than the alkaline ones, approximately 7kg each for the fore and aft battery assemblies compared to about 9kg. Ballasting is done by adding/removing lead weights, ballast bottles of lead shot distributed throughout the glider and metal plates in the science bay. It is usual to take three attempts before ballasting is perfect. The initial stage is best if the glider is too heavy. Note that if seawater is used it should have been recently replaced and of a similar temperature and salinity to that expected in the deployment area. To set the glider into its neutral state the vacuum must be applied, the pitch battery position = 0 and oil vol = 0. The easiest command to do this is `ballast`.

The stability of the glider is determined by the h-moment. This is the distance between the centres of buoyancy and mass in both the vertical and horizontal planes. If the h-moment is too small then the glider will be too twitchy and very sensitive to changes in pitch and roll, potentially oscillating. If the h-moment is too large then the glider will be too stiff and harder to maneuver. Webb suggest that the h-moment should be between 5 – 7 mm. To calculate the horizontal h-moment the glider needs to be rolled. If the glider is too heavy this is easily achieved using a piece of string under the wing mounts. If the glider is neutrally buoyant then a mass is dangled off one mount while a spring balance is attached to the other. The fore-and-aft h-moment can be easily checked by making sure the fwd battery is set to 0 inches (put `c_battpos 0`) and noting the pitch of the glider. If the pitch battery only needs to be adjusted by approximately 0.2” (the minimum) then that is within acceptable limits. The pitch battery should be able to cause the glider to change attitude from nose down to nose up.

The recently published operator's manual has worksheets for ballasting, although simple physics calculations seem to suffice.

The aft battery pack has an awkward mounting. The idea is to be able to set the roll to 0° . This is not as easy as it could be. If the roll can be brought under 2° that is acceptable, pencil marks on the mountings help. The roll is measured using `get m_roll` or better, to start logging data (`logging on`) in a `.dbd` file, download the file and view with IGLOO. Leave stable for at least 5 minutes in order to view the roll on the IGLOO application.

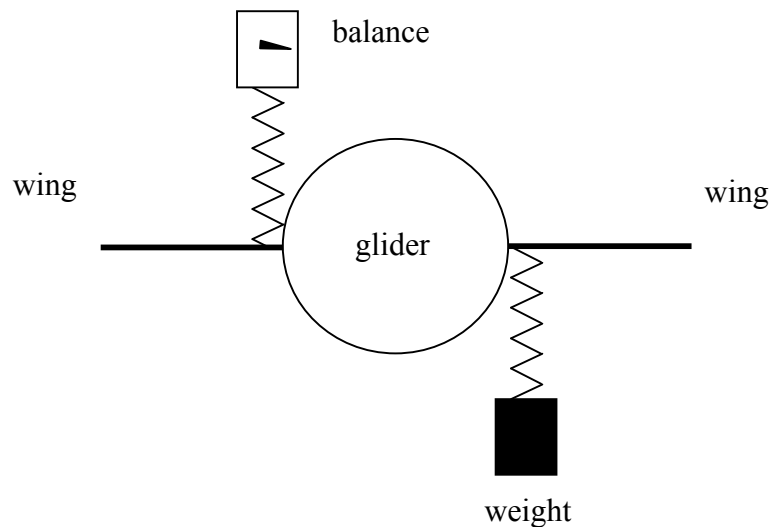


Figure 5.6 *How to measure the roll (adapted from the Operator's Manual)*

Care needs to be taken when attaching the fwd battery pack to the worm drive of the pitch motor. This is easily cross-threaded or not bedded down correctly. It helps to have the nose cone loose when sliding the battery inside the hull casing.

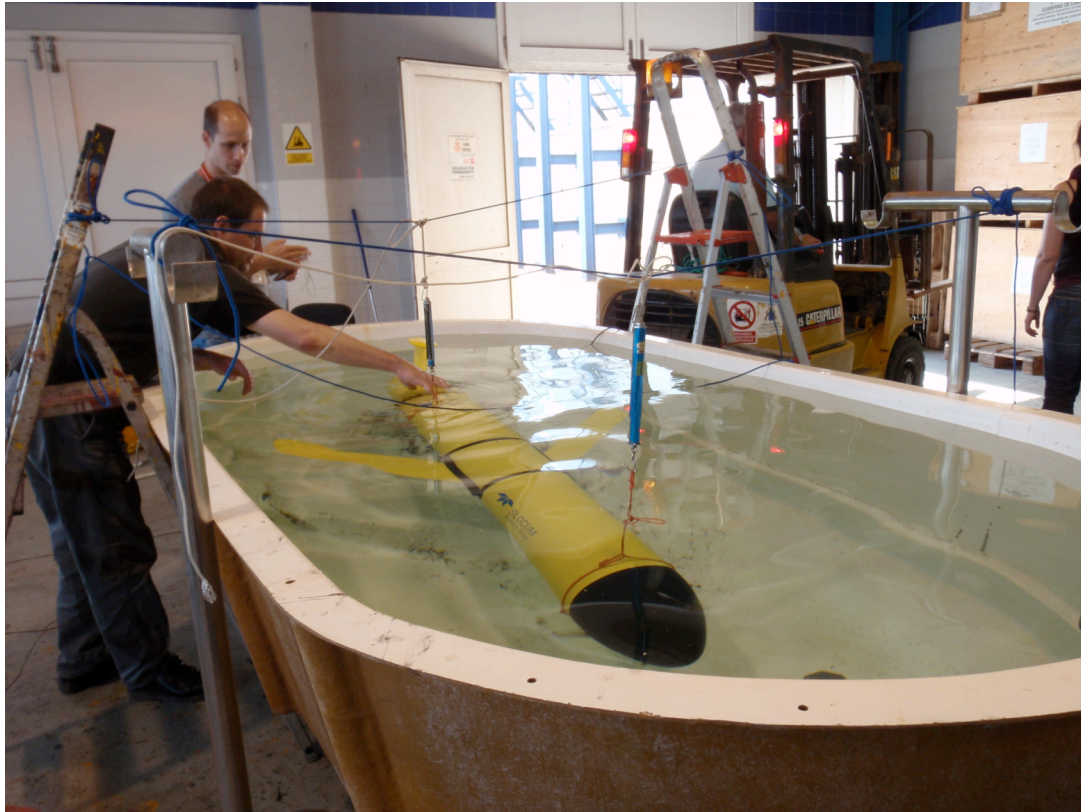


Figure 5.7 *The glider suspended in a tank with newtonmeter balances. Note that the glider is not yet ballasted correctly and out of trim.*

5.5 Mission Planning

Before deployment it is a good idea to program a couple of waypoints that will hold the glider a few nautical miles offshore in deep water overnight to establish that the glider is functioning correctly, within easy reach of a RIB, and preferably in reach of the FreeWave radio. Once you are confident that the glider is all ok, then new goto_150.ma and a yo_50.ma files can be uploaded via either FreeWave or Iridium to take the glider to the area of interest. Allow for the time required to get to and from the main area. This is a good time to experiment with the parameters such as altitude sensor, timeout, pitch, number of yos, tidal correction... It is important to be sure that any possible tides or currents will not carry the glider ashore, or even into shallow water.

autoexec.mi	Lists all details about the glider and switches on/off sensors/devices.
rapid.mi	The basic program for running the rapid mission
goto_150.ma	This lists the waypoints and how the glider should steer towards them: looping, sequentially, correcting for current or by rudder angle.
yo50.ma	This describes the vertical behaviour of the glider, e.g. number of 'yos', pitch angle, depth and volume of oil displaced.
surfac50.ma	This is the normal surface routine that takes over for the last 20 m of the ascent.
surfac51.ma	This is the abort surface routine.

Table 5.1 *Mission files*

There are two basic types of files; mission (mi) and mission acquisition (ma) files. Effectively the ma files are subroutines are read by the mi file and describe the vertical profile, abort behaviours and the navigation of the glider. It is good practice to edit the ma files to pilot the glider instead of the mission files. These files are edited and stored on the dockserver computer in the to-dockserver directory. They can be edited using *vi* and viewed using *less* or *more*. Examples of mission files can be found in Appendix A.

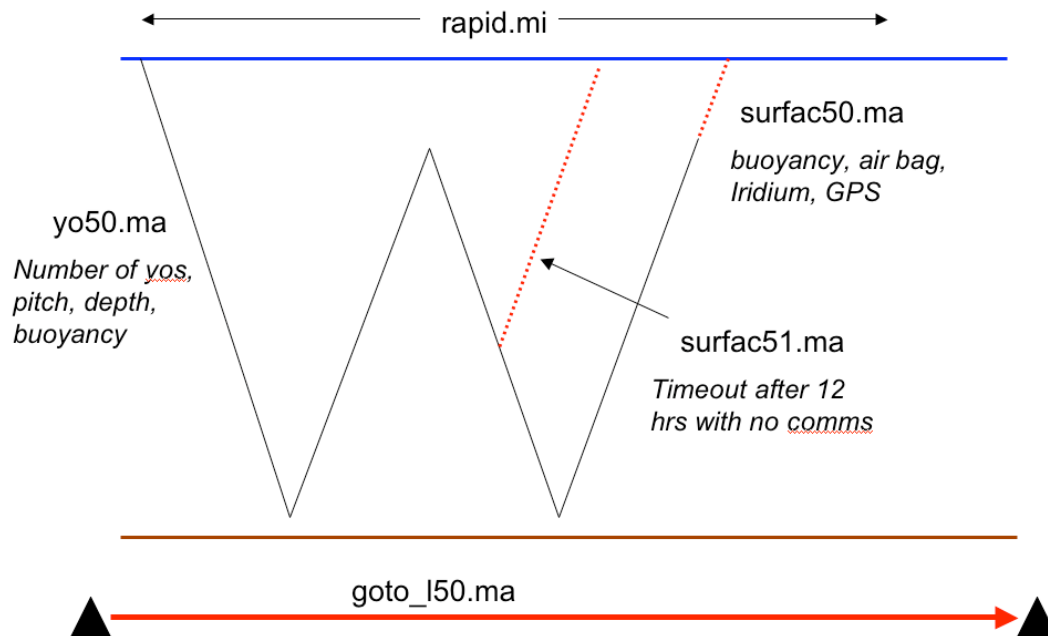


Figure 5.8 *Schematic of the Mission profile and the routines.*

5.6 Deployment

ONCE THE GLIDER HAS LEFT THE LAB/WORKSHOP NEVER USE PICODOS OR GLIDELAB OR USE – IRIDIUM!!!

Reference: Operator's Manual pages 111 – 116

Prior to deployment power up the glider and connect with FreeWave. Use the `callback 30` command to disable Iridium and put `c_air_pump 0` to switch off the air bladder. Run the mission `status.mi` which tests all the systems.

Once it is confirmed that the glider is functioning power down and replace the green plug with the red dummy. Place aboard the RIB for deployment.

At the deployment site power on the glider once again and establish communication with FreeWave using `^C`. Again temporarily disable the Iridium with `callback 30` but leave all other systems running. With the tether and buoy attached lower the glider into the water. She should float! Run the `overtime.mi` mission using `run overtime.mi`.

The glider should slowly dive and proceed on course for the period of time determined by the mission plan and then surface. The buoy should show the motion of the glider. IF it does not surface recover the glider and abandon the deployment!

If you are confident that the glider is behaving herself, connect to Iridium and check that the communication link works. Then sign off using the `callback` command. Untie the tether and using FreeWave run the mission using `run rapid.mi`.

5.7 During Mission – Changing Parameters

The glider is normally piloted by changing the mission files. E.g. changing waypoints or buoyancy engine parameters. It is best to have the edited files ready to be sent directly to the glider in the `localuser@dockserver/gliders/dynamite/to-glider/` directory prior to communication with the glider. This is effectively an ‘outbox’ to send ‘email’ to the glider. Before any `.mi` or `.ma` file is edited it should be copied and renamed to leave a historical record of edits.

i.e. `goto_150.ma` → `goto_150.ma.1`.

Keeping the ‘working’ filename the same also avoids having to change other routines already aboard the glider. If no-one is likely to be present or the internet connection is likely to be poor when the glider is scheduled to surface a XML script can be run using the GliderTerminal that will automatically upload the contents of the `to-glider` directory. However, it is important that after the files have been uploaded to reset the XML script back to the normal version so that the next time the glider surfaces it does not try to upload an empty directory and cause an error. Additionally, for the benefit of other users and the webpage, copy the updated file to the `dynamite/current_config` folder.

There are three methods of doing this based on the communication methods outlined in section 5.2.

- 1 If the file is already on the dockserver then it is a question of copying and editing it and moving it to the `to-glider` directory. Move the file to the `/to-glider` directory using any working method (e.g. command line or mc or GUI)
 e.g. `cp to-dockserver/goto_150.ma`
 `gliders/dynamite/to-glider/`
 When contact has been made the GliderTerminal command to upload the entire content of
 the ‘outbox’ is:
 `dockzr *.*`
 It is a good idea to check that the edited files have arrived ok.
- 2 Logging on to the dockserver from anywhere:
 Install and run *putty.exe* (easily found by google)
 Setup details: name (e.g. `glider-dockserver`), port = 22, host = `ssh.noc.soton.ac.uk`, SSH tunnels = `dockserver:6564, dockserver:6564, 5901` and `dockserver:5901`
 This gets you into the NOCS server. To get into the dockserver first login as yourself with usual username and password and then:

```
ssh localuser@dockserver
Password: *****
cd /gliders/dynamite/ as above
```

dynamite has 4 sub-directories: to-glider, logs, from-glider and gliderState.xml. Then use GliderTerminal as before.

- 3 VNC method which gives you control of the screen at the dockserver PC as localhost.
Install and run *putty.exe*, and log on as above
Run VNC password: *****
This will produce a screenshot of the dockserver, although quality is not great AND the audible alarm does not function! The advantage of this is that more than one viewer can see the same page and the same information therefore great if problem solving needs to be done over the phone.

5.8 Viewing Data and Positions During a Mission

There are three easy methods of viewing the glider during deployment: using the website set up by Lucas at the NOC, using SSH to the dockserver and GliderTerminal or via VNC (or similar) to the dockserver.

- 1 SSH Method: use *putty.exe* to log on to the dockserver as 'localuser'. Then open GliderTerminal and wait until the glider surfaces. An audible alarm sounds when there is communication.
- 2 VNC Method: use *putty.exe* to log on the dockserver as above. Open VNC viewer to take control of the laptop hosting dockserver in David Smeed's office. This has the advantages that more than one person can see the same screen and that there is a history of what has happened. The main disadvantage is that there is no alarm, so it maybe a good idea to open GliderTerminal on the local computer as well.
- 3 Website: This is great as it shows the shortened data directly and produces an eta of the next surfacing, and a visual of the location of the glider. However, it is only updated on the hour and you cannot interact with the glider.

With either of the direct-to-dockserver methods it is possible to run a GUI program 'igloo.py' written by Lucas to view the downloaded data files. This is straightforward to use. Igloo can be run by typing *igloo.py* into the terminal window of the dockserver. To run it independently on another machine requires python (and probably Linux) to be installed first. Lucas has put the full installation guide for both Python and Igloo on the Glider website.

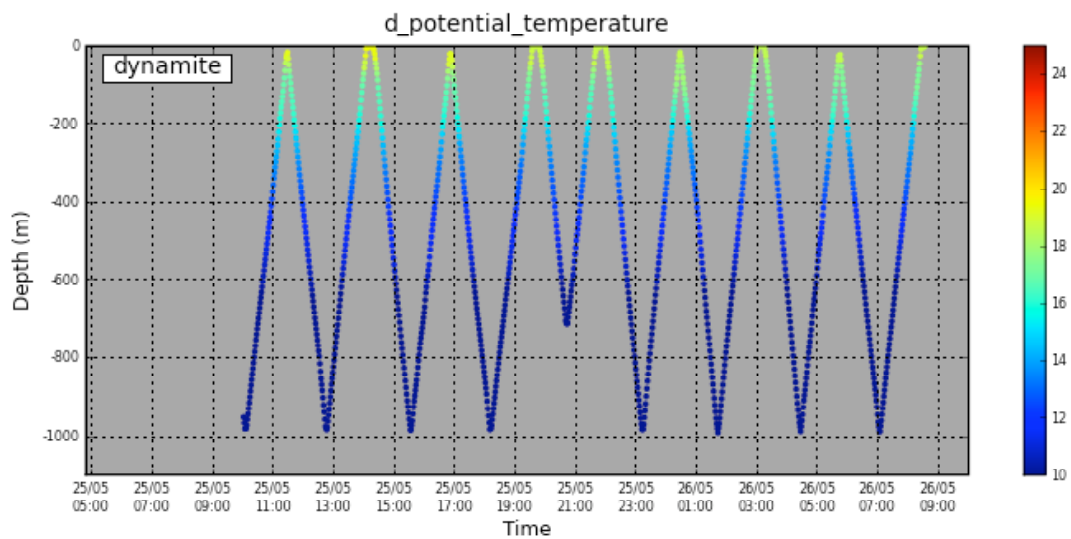


Figure 5.9 Screen shot of sample data from the website showing the derived potential temperature. This is based in the Igloo application.

There are 4 types of data file, shown below, each time a new segment of the mission starts a new file is created. Usually, only the .sbd and .mlg files are sent back via Iridium.

- .sbd Short Binary Data file - Records only specified sensors (SBDLIST.DAT) to reduce Iridium time/costs
- .dbd Dinkum Binary Data file – Records ALL sensors that have been turned on.
- .mbd Medium Binary Data file – records those sensors specified in the MDBLIST.DAT file
- .mlg Mission Log file – tracks the calls for behaviours and instructions back and forth between dockserver and the glider. Records the details of an abort.

These mission data files are sequentially numbered. On connection the relevant files are sent to the dynamite from-glider folder and renamed to avoid possible conflicts of names with other glider data files.

The .sbd (and .dbd files on completion of the mission) files can be downloaded from the dockserver by ftp. Once the .sbd are sent to the dockserver by the glider the dockserver renames them using a standard algorithm. Any one of the .sbd can be downloaded for viewing, but to make sense of them the first one must be downloaded too as this contains the metadata and the variable names! Once the files are downloaded they need to be converted to ASCII format or more usefully, MATLAB format. (see Sections 8 and 11).

6 The First Deployment – *Bellamite*

David Smeed

The glider *Bellamite* was successfully deployed 17th September 2008 and recovered 24th November 2008 and the vehicle and its sensors operated continuously during the deployment. A map illustrating the deployment and operating locations is shown in Figure 6.1. A complete dataset was obtained. There were though a number of difficulties encountered during the trial:

- Two problems were encountered using the altimeter to detect the bottom. (Previous NOCS deployments had all been in deep water with the altimeter turned off to save power). The first was that the glider would sometimes detect a false bottom. Analysis showed that the most likely cause was scattering from zooplankton. This was corrected by changing a software parameter to disregard the bottom if it was less than 8m away (the sound reflected from zooplankton is only detected when the scattering layer is very close to the glider).
- On a number of occasions the glider failed to detect the bottom and the vehicle “landed”. This was shown to be a software bug and it was not possible to fix this at the time. Instead the sampling strategy was changed so that the glider tracks ran along isobaths rather than across them. The manufacturer has now resolved this problem.
- Iridium communications was often very poor. This problem was significantly worse than experienced during our previous deployments and on some occasions no data was received from the glider for 36 hours or more. Discussions with other Iridium users suggested that the problem was probably due to the routing of telephone calls from the Iridium ground station (which depends on the location of the glider) to the modem on the server at NOCS that receives the calls.
- The glider slowed down significantly during the mission (Figure 6.2). The glider changes its buoyancy by pumping oil from inside the hull to an expandable bladder on the outside of the hull (but within the flooded nose cone). Diagnosis of previous deployments has shown that air can enter into the buoyancy pump thus affecting the volume of oil that is pumped. On this deployment the problem became significantly worse and there was a large reduction in the speed of the vehicle. It was decided to leave the measurement site early to allow sufficient time for the return to Gran Canaria. The manufacturer has since changed the membrane used for the oil bladder.

6.1 Data

A detailed analysis of the data quality has been completed and is described in a report by Merckelbach, which forms Section 7. Here the main findings are summarized. Previous glider deployments by NOCS had been in winter in the northwest Mediterranean. There the temperature gradient was very weak, varying by little more than 1°C in the upper 1000m. In contrast the temperature at the RAPID site varies by over 14°C. This large thermal gradient highlighted a problem with the glider CTD whereby thermal inertia of the CTD duct and conductivity sensor results in inaccurate salinity calculation. However, a correction for this effect can be calculated and applied.

After correction for the thermal inertia effect the glider data were compared with data

from the moorings. The initial comparison showed that a small correction needed to be applied to the conductivity measurements from the glider CTD. All CTDs require calibration, however, the way the CTD is mounted on the glider makes this difficult to do in the laboratory and comparison with other instruments is currently the best way of doing this. If gliders are to be used in the RAPID-WATCH monitoring array it is important to ensure that calibration will be possible by inter-comparison with other instruments. The calibrated data was found to be in good agreement with the data from moored instruments and the small differences can be accounted for by variability from small-scale internal waves.



Figure 6.1 Chart of the Bellamite deployment, including the locations of the moorings EBH3, EBH4 and EBM1 (taken from the NOCS glider website)

6.2 Sampling issues

Data collection from gliders is different to that from moored instruments. The moored instruments are located at a small number of discrete vertical levels but each instrument is able to sample rapidly in time (once every 30 minutes). In contrast gliders are able to achieve a high-resolution sampling in the vertical (typically every 0.5 to 3m depending on the sampling rate). However, the time resolution at any single level is much less typically 1 to 4 hours depending on the speed of the glider and the depth of the profile. Thus using a glider reduces the errors associated with interpolation in the vertical but will increase the errors associated with temporal interpolation. There is significant internal tide on the continental slope and so it is necessary to resolve the tidal signal in order to obtain unbiased daily mean profiles of temperature and salinity required for the calculation of the MOC. This sets the minimum vertical speed of the glider.

Work is currently underway to adapt techniques developed for tidal analysis of data from profiling CTDs to glider CTD data to improve the daily mean profile estimates. An initial

trial has been made substituting glider data for mooring data in the algorithms for calculating the MOC (see Chapter 8) and a quantitative analysis of the resulting MOC estimates will be made once the improved daily means are available.

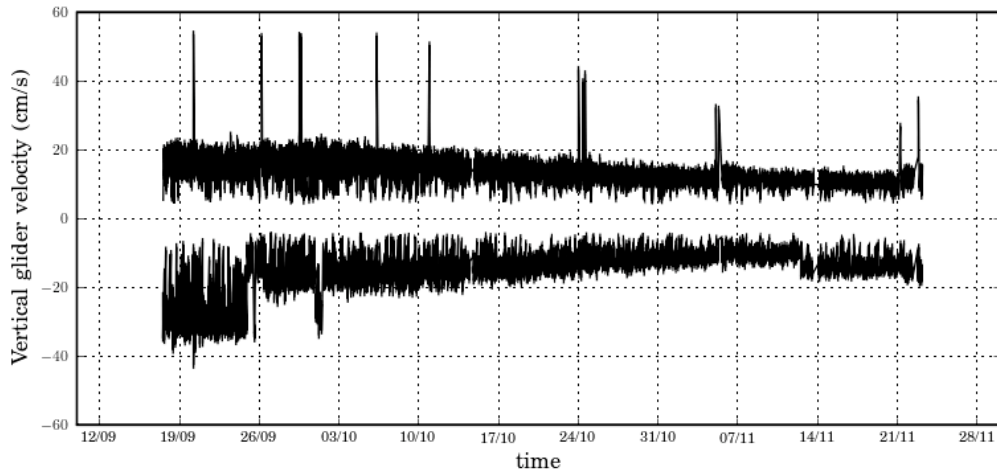


Figure 6.2 Vertical speed of glider Bellamite during the first trial. Rapid changes of speed were when commanded by the changing the mission variables. The slow decrease between 17th October and 13th November is thought to be due to air in the buoyancy engine.

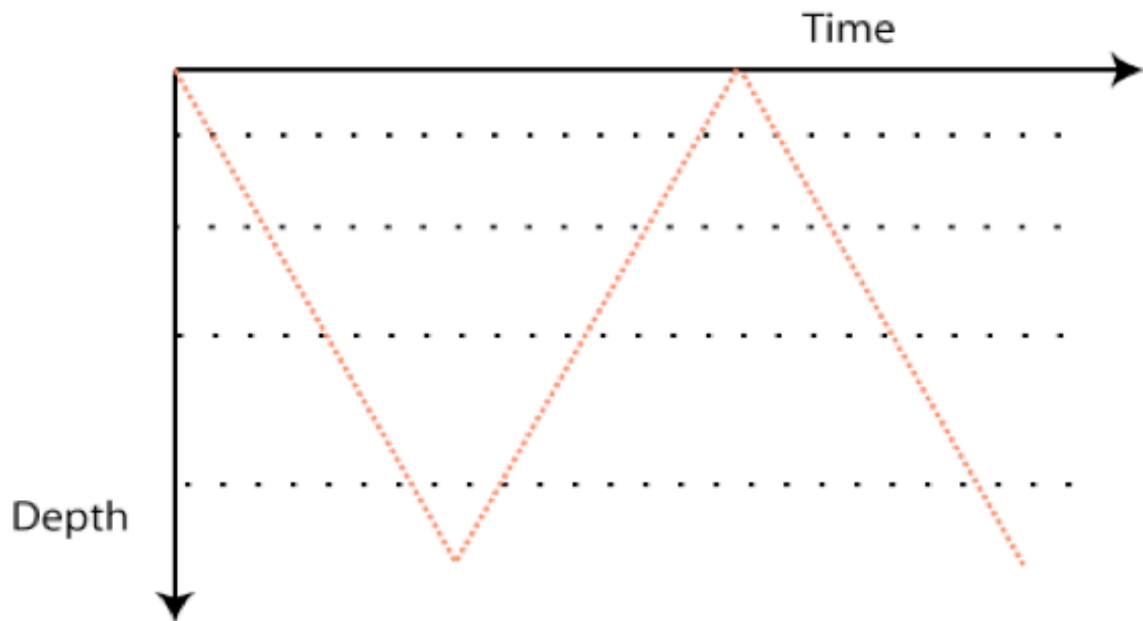


Figure 6.3 Schematic to highlight the differences between the glider and the moored MicroCATs sampling. The glider samples more often and over the full depth, while the MicroCATs sample every half hour at relatively fixed depths (subject to current induced mooring motion).

7 CTD Measurements from Glider *Bellamite*

Lucas Merckelbach

Originally prepared as appendix for progress report "The use of autonomous underwater gliders as part of the Rapid system for monitoring the meridional overturning circulation" by David Smeed, Lucas Merckelbach, Paul Wright, Gwyn Griffiths and Stuart Cunningham

7.1 Introduction

The glider *Bellamite* was used in a trial project for the RAPID Watch programme to measure salinity and temperature between the Canary Islands and the main land of Morocco. The mission started on 17th September and lasted until 24th November 2008. Both the deployment and recovery were made about 10 nm East of the village Telde on Gran Canaria, Spain, with generous help from staff of ICCM and one of their research vessels. After deployment the glider went eastward, to the south of Fuerteventura and up the slope of the Moroccan shelf. Here it was planned to do a cross-shore section visiting moorings EBH3, EBH4 and EBM1 (Figure 6.1). Unfortunately, due to technical problems with the altimeter, the glider's waypoints had to be reprogrammed to do a section along the 1000 m isobath, passing mooring EBH4 on its way. Figure 6.1 shows the trajectory of the glider *Bellamite*, including the approximate locations of the relevant RAPID moorings. The latitude and longitude as function of time is shown in Figure 7.1. The locations of the moorings EBH3, EBH4 and EBM1 are shown as well. It is seen that the glider passed mooring EBH4 closely on about 15 occasions, but the other two moorings much less frequently.

The only sensor on board was a Seabird 41 CTD (modified for gliders). In this document, the salinity and (potential) temperature data are examined. Usually, the temperature sensor of the CTD is quite stable, but the conductivity cell may require calibration by applying a multiplication factor and offset to the raw conductivity reading. In addition, CTDs generally suffer from thermal inertia, which, if not corrected for, introduces an error in the salinity calculated from conductivity and temperature data. The previous deployments of the NOCS gliders were during winter in the northwest Mediterranean where temperature gradients were relatively weak (temperature usually varied by less than 1°C in the upper 1000m), and so the thermal inertia effect was small. In contrast the temperature varied by 10°C or more at the site of the RAPID deployment. Here we look at two methods to correct the CTD data. The thermal inertia corrected CTD data are subsequently calibrated against CTD data gathered with the RAPID moorings EBH3, EBH4 and EBM1.

7.2 CTD Measurements

The glider uses a buoyancy engine as propulsion and so the vehicle must always follow a saw-tooth profile through the ocean. A typical profile of the glider consists of two yo's to 1000 m (or less in shallow water). Vertical speed is of the order of 0.2 m/s and the profiles are completed in about 8-10 hours. The forward speed is typically 1 km/h or roughly 25 km/day. The CTD was programmed to measure both on the up and down casts at an interval of about 20 seconds.

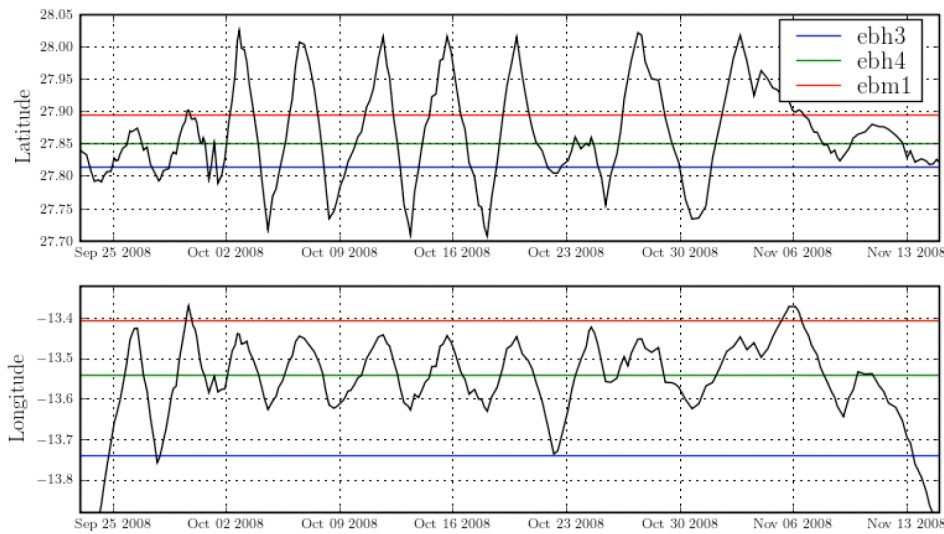


Figure 7.1 *Glider's latitude and longitude versus time, including the positions of the moorings EBH3, EBH4 and EBM1.*

7.2.1 Calculation of Salinity

Salinity (S) and potential temperature (θ) can be calculated from conductivity, temperature and pressure. In the ideal world, all three components are measured instantly and without error. In practice, however, in particular salinity and (potential) density data can be erroneous when calculated from raw conductivity, temperature and pressure data. The three main causes for erroneous salinity and density data are (Lueck, 1990) a) different response times of the conductivity cell and the thermistor, b) a physical separation between the conductivity cell and the thermistor, and c) thermal effects to the conductivity cell due to thermal inertia of the duct of the CTD. The response of both the conductivity cell and the thermistor to a physical signal (temperature or conductivity) can be modelled by a rate equation. For temperature, for example, we can write Johnson et al. (2007)

$$\dot{T}_0 = \frac{1}{\tau_p}(T_i - T_0) \quad (7.1)$$

where T_i is the true temperature (ingoing signal), T_0 the reported temperature (outgoing signal) and τ_p the response time of the instrument. It appears that the response times for the thermistor and the conductivity cell are about 0.5 s and 0.1 s for the CTD41CP (Johnson et al., 2007), respectively. The CTD41CP is technically equivalent to the glider CTD, except that the glider CTD is unpumped. Water flows through CTD and the internal flow speed may vary thus affecting the response times. However, it is thought that the response time will still be less than 1 second. As the glider's fastest sample rate is 0.25 Hz, this effect is considered to be insignificant. In the present study, the glider sampled at 20 second intervals, so that the response lags are certainly negligible.

The thermistor is located at the beginning of the duct, whereas the center of the conductivity cell is located about 10 cm 'down stream'. Assuming the flow rate inside the duct is the same as the glider speed, i.e. 20-30 cm/s, the time required for a water

parcel to pass from the thermistor to the conductivity cell is about 0.5 second or less.

The third and most significant effect is due to thermal inertia: a change in water temperature can yield heat exchange between the water sample in the duct and the duct wall. The temperature of this water parcel can be different from the temperature as measured by the thermistor. This temperature change affects the conductivity of the sample.

A detailed account of this effect is given by Lueck (1990). He proposes a method to correct the conductivity of the sample from the observed change in temperature. In short, he argues that a step change in temperature causes an immediate response in the conductivity signal equal to $1 - \alpha$ of the eventual (associated) conductivity change. The difference, α , which is of the order of 10-20%, decays exponentially with a time scale of the order of 10 seconds.

Another approach, which is similar to that proposed by Lueck, does not have an immediate response of the conductivity sensor, but instead assumes that the temperature difference between the thermistor and the location of the conductivity cell decays exponentially. Here we implement and discuss both approaches, starting with the latter.

7.2.2 Approach 1 - Adjusting Temperature

If the CTD instrument passes through a sharp thermocline, we can idealise that as a temperature signal with a step change at $t = t_0$. From $t = t_0$ onwards the temperature is assumed to decay exponentially with time to approach the asymptotic value of temperature after the step. We can model the difference between corrected and measured temperature by convolving the impulse response function

$$h_T(s) = \begin{cases} 0 & \text{if } s < 0 \\ a \exp(-s/b) - \delta(s) & \text{if } s \geq 0 \end{cases} \quad (7.2)$$

where $\delta(s)$ is the Dirac delta function, with the measured temperature. The parameter b represents relaxation time due to the thermal inertia of the CTD duct and the parameter a is to ensure that

$$\int_{s=0}^{\infty} a \exp(-s/b) ds = 1 \quad (7.3)$$

For high resolution data ($\Delta t/b \ll 1$), $a = 1/b$, but for low resolution data, equating a and $1/b$ causes significant errors due to discrete integration. The temperature correction T_c can then be written as

$$T_c(t) = \int_{t-\Delta T}^t h_T(t-\tau) T(\tau) d\tau \quad (7.4)$$

where T is the measured temperature, t is time and τ is the integration variable. The parameter ΔT is the integration window, and $\Delta T \gg b$. To evaluate the integral in (7.4), the temperature signal is subsampled at 1 Hz by linear interpolation.

Note that the sign of the temperature correction is dependent upon the temporal

gradient of temperature. This has opposite signs for up and down casts. Thus when temperature is not corrected there will be an error in salinity that will have a different sign on up and down casts. This can be used to determine the temperature correction.

Once the coefficients a and b are determined, the salinity and potential temperature can be calculated as

$$\begin{aligned} S &= P_s(T + T_c, C, P) \\ \theta &= P_\theta(T, S, P, P_{ref}) \end{aligned} \quad (7.5)$$

where P_s and P_θ are standard polynomials (see the Seawater Package for Matlab, for example), and P_{ref} is the reference pressure for the potential temperature. Note that the corrected temperature is used only in the calculation of the salinity.

Determination of the Time Constant

In order to find optimal values for α and b , we developed an error minimisation procedure. The assumption is that, when all errors are corrected for, the data from a down cast and subsequent up cast render a unique curve in $S - \theta$ space. For a given pair (α, b) , both S and θ are computed. The data are re-ordered such that θ is monotonically increasing. A third-order smoothing spline is fitted through the data. The total squared error in salinity is a measure of uniqueness of the $S - \theta$ curve, giving the optimal (α, b) for the minimum total squared error. An example of a fit to estimated S and θ data is shown in Figure 7.2.

Setting the time window for integration, Δt to 400 seconds (corresponding to a window length of 20 samples, sampled at 21 seconds intervals), the computation is fast enough to find b by trial and error. For values of b around 4 seconds, we clearly see that the up and down casts converge to one curve in $S - \theta$ space.

Calculating the total squared error in salinity for a range of relaxation times results in the graph shown in Figure 7.4. The minimum error is found for a relaxation time of 3.65 seconds.

The potential temperature and salinity are recalculated after filtering the in-situ temperature according to (7.2) with $b = 3.65$. The results are shown in Figure 7.4. The top panel shows that the scatter has reduced significantly. The zooms (middle and bottom panels) show that the hysteresis has mostly disappeared: the up and down casts are now indistinguishable.

The effect of the glider speed on the through flow rate could not reliably be quantified. The strong fluctuations in the measured glider speed (measured from depth rate and pitch angle), adversely affected the quality of the correction, making it in many cases even worse than the uncorrected data. The correction improves if the glider velocity is linearized per down and up cast. Since there is little variation in glider speed anyway, and the improvement is not significant, the effect of the glider speed is further not considered.

7.2.3 Approach 2 - Adjusting Conductivity

A slightly more complex filter is due to Lueck (1990) to which the reader is referred for the details of the theory. Rather than convolving the measured temperature with an impulse transfer function to obtain a corrected temperature, the measured temperature is

convolved with a (different) impulse transfer function to obtain the conductivity correction C_C

$$C_c(t) = \int_{t-\Delta T}^t h_c(t-\tau)T(\tau)d\tau \quad (7.6)$$

where the transfer function h_C is given by

$$h_c(s) = \begin{cases} 0 & \text{if } s < 0 \\ \gamma\alpha[\delta(s) - a \exp(-s/b)] & \text{if } s \geq 0 \end{cases} \quad (7.7)$$

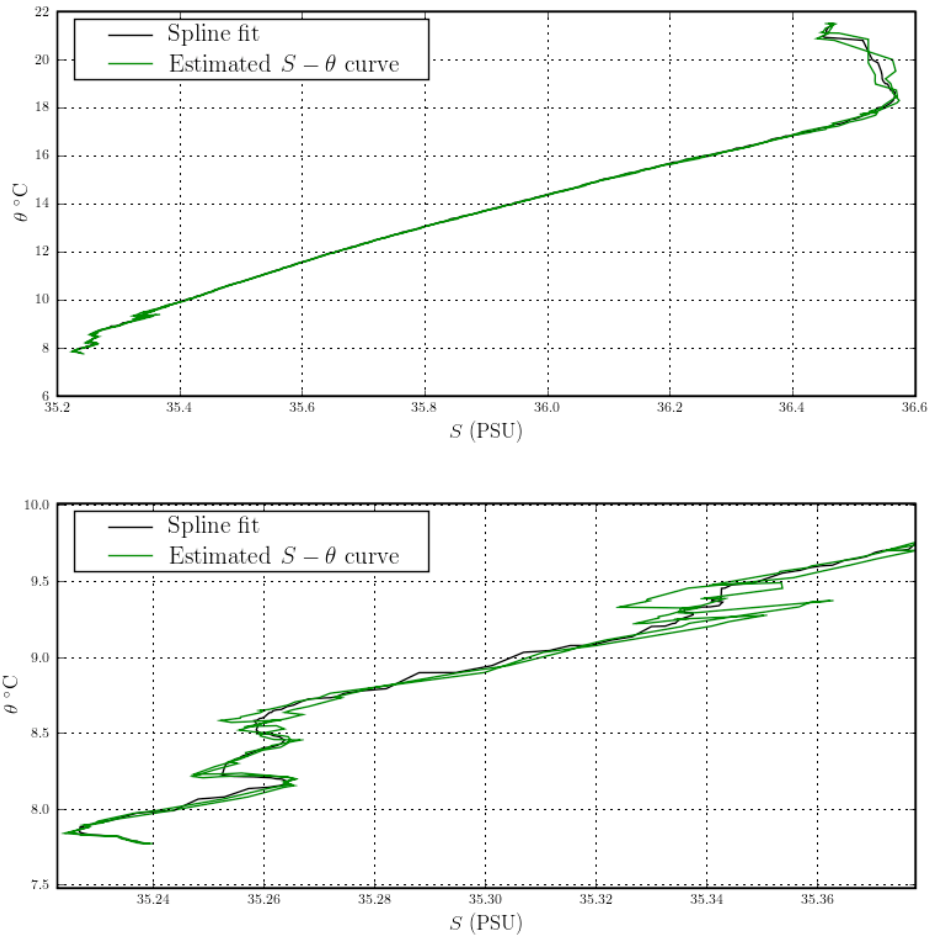


Figure 7.2 $S - \theta$ curve for one up and one down cast (green) of uncorrected data and a spline fit to the data (black). The lower panel shows the deep water only.

where α the initial error as explained above and

$$\gamma = \frac{\partial C}{\partial T_{s,p}} \quad (7.8)$$

The factor γ merely acts as a scaling factor, the value of which is close to 1 mS/cm $^{\circ}\text{C}$. In a similar way, the salinity and potential temperature can now be calculated as

$$\begin{aligned} S &= P_s(T, C + C_c, P) \\ \theta &= P_0(T, S, P, P_{ref}) \end{aligned} \quad (7.9)$$

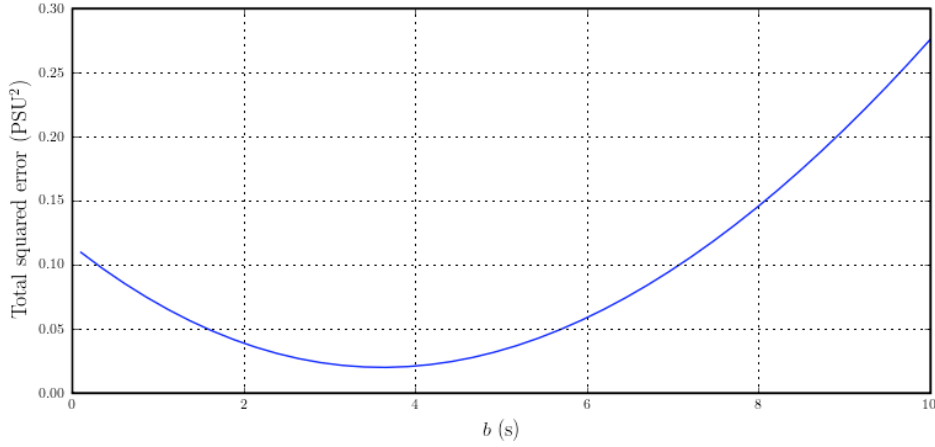


Figure 7.3 Total squared error as function of b .

Parameter Identification

The value for α depends on the flow rate inside the duct and therefore is potentially related to the glider speed, whereas according to Lueck (1990) the relaxation time is not. Johnson et al. (2007) found that for a pumped Sea-Bird CTD41CP $\alpha \approx 0.15$. However, flow rates for a pumped CTD are possibly 10 times higher than for the non-pumped version. So, we expect α to be significantly higher than 0.15, but we cannot make any *a priori* estimate.

The minimisation method employed above is also used here to find the optimal estimate for the $S - \theta$ curve, the total squared error in salinity between the spline fit and estimated $S - \theta$ curve is shown in Figure 7.6. A minimum error is found for $\alpha = 0.23$ and $b = 18$ s, however, a band with errors close to the minimum error is observed, suggesting that the final result is not critically dependent on the actual combination of α and b . The black line in Figure 7.5 is an empirical relation between α and b , given by

$$\alpha b = 4.14 \text{ (s)} \quad (7.10)$$

Figure 7.6 compares the corrected $S - \theta$ diagrams for two different settings for α and b , satisfying the empirical relationship. Both curves are almost identically; only for $\theta \approx 20^\circ\text{C}$ small differences can be observed.

Figure 7.7 shows $S - \theta$ diagrams from raw and corrected data for $\alpha = 0.24$ and $b = 18$ s. It can be seen that the correction procedure leads to the almost complete collapse of data from the down and up casts to a single curve. Figure 7.9 shows raw and corrected salinity and potential density profiles. A pycnocline can be observed near 30 m depth. The salinity also increases relatively strongly with depth. The raw data show a local decrease in salinity and potential density, characteristic of a conductivity/temperature mismatch (Lueck, 1990). These local decreases are eliminated by the correction procedure, yielding a stable potential density profile.

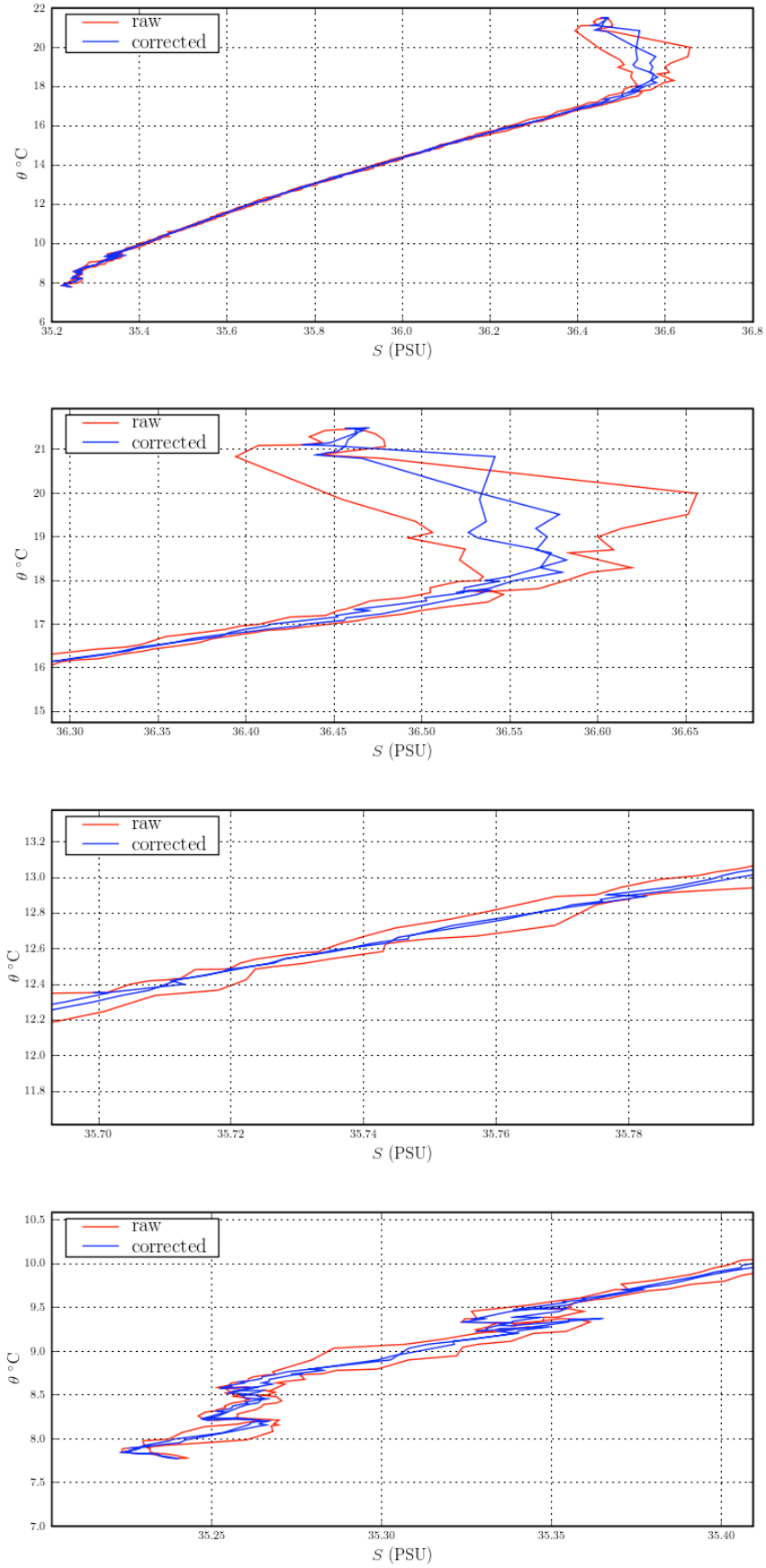


Figure 7.4 $S - \theta$ diagrams from raw and corrected data (temperature adjustment) for a single yo profile (29 Oct 2008). The upper panel shows all data, the other panels show a selection only.

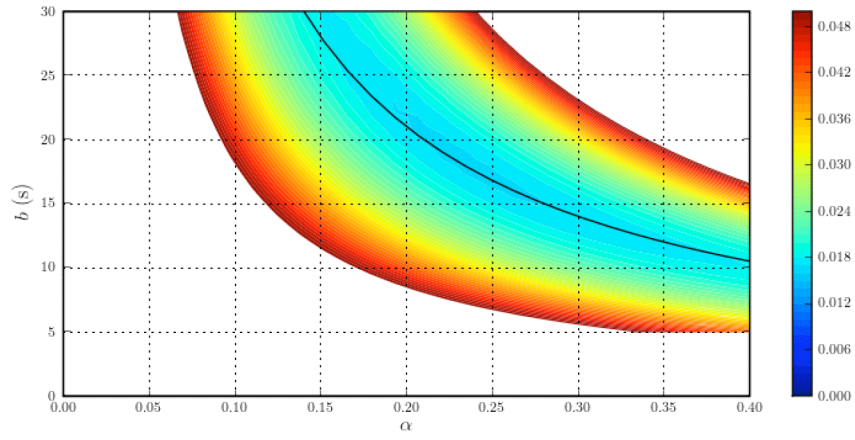


Figure 7.5 Total squared error in salinity as function of α and b . The black solid line is given by $b = 4.14/\alpha$.

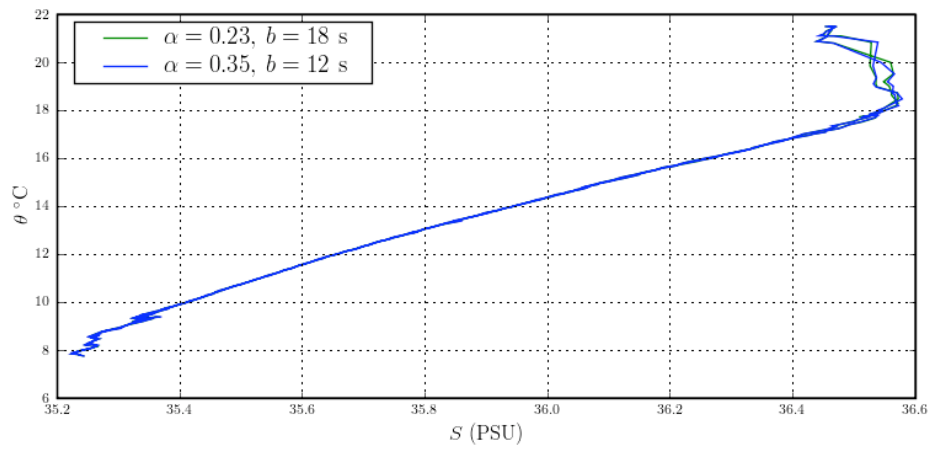


Figure 7.6 Corrected $S - \theta$ diagrams for different α and b .

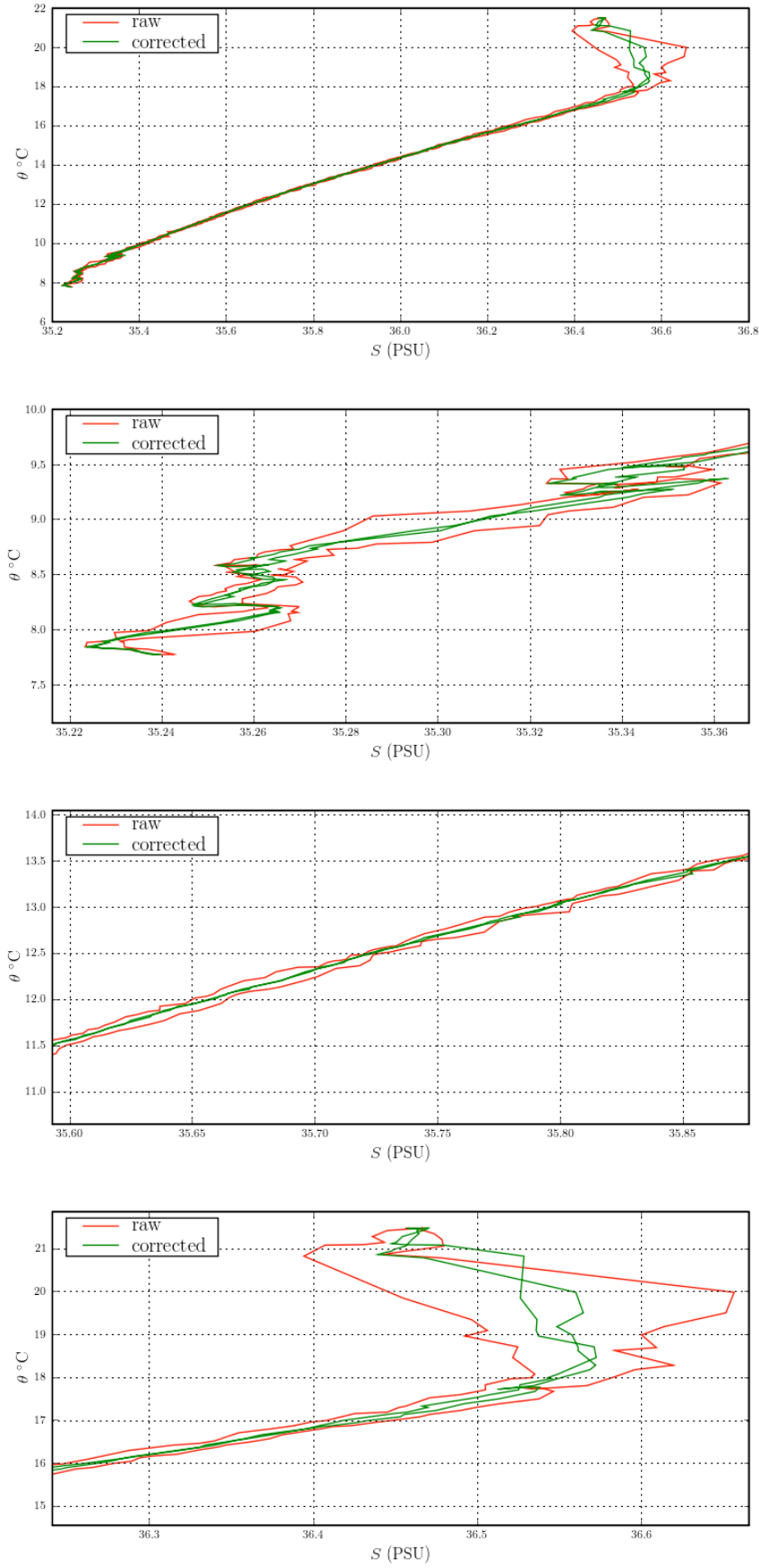


Figure 7.7 *S - θ diagrams from raw and corrected data (conductivity adjustment) for a single yo profile (29 Oct 2008). The upper panel shows all data, other panels show a selection only.*

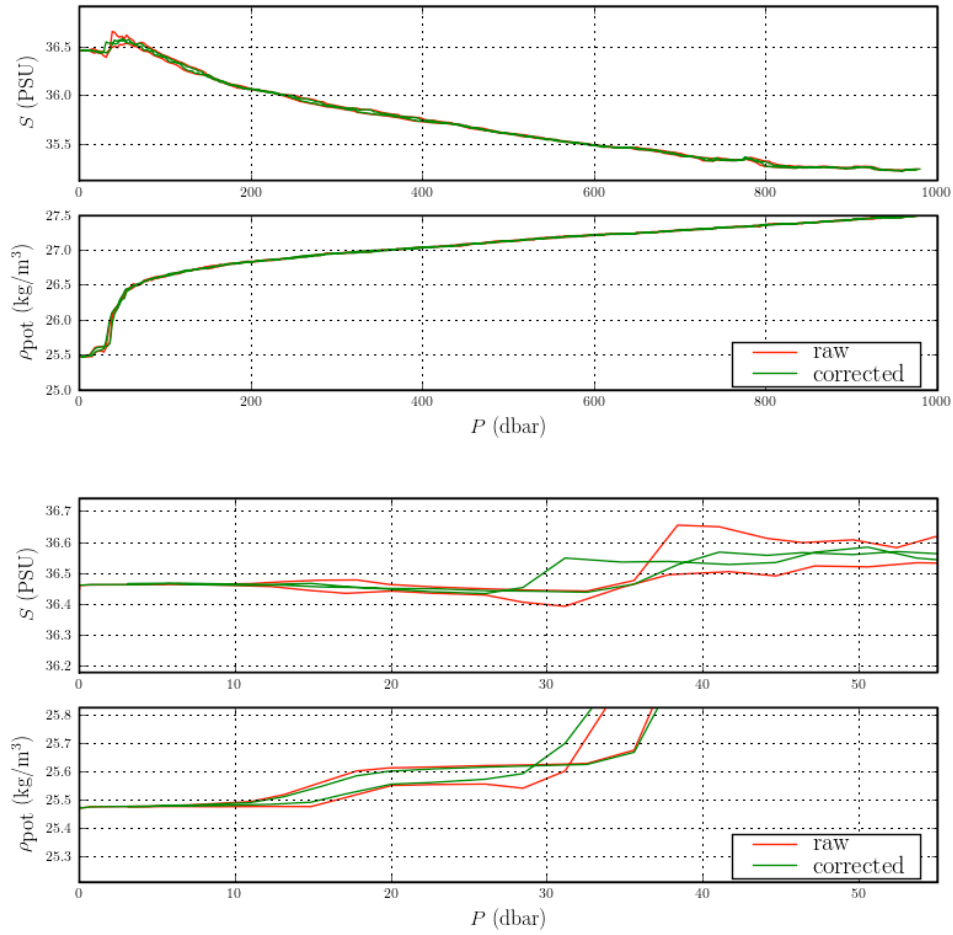


Figure 7.8 Salinity and potential density profiles for raw and corrected (conductivity adjustment) data for a single yo profile (29 Oct 2008).

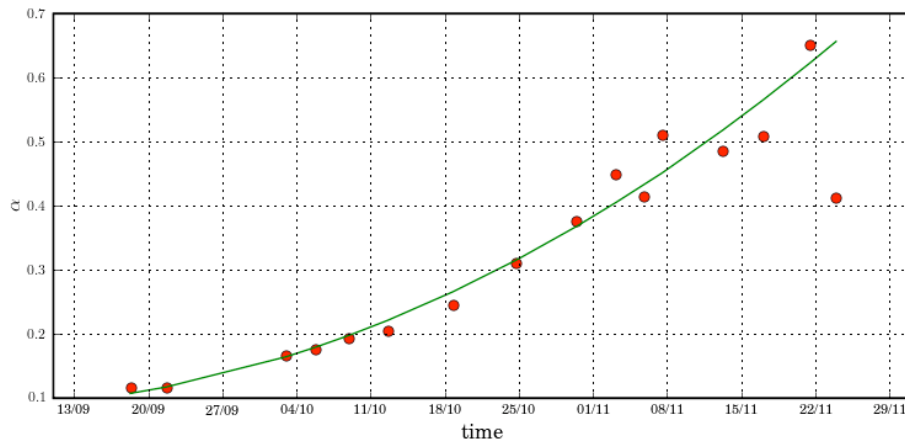


Figure 7.9 The optimal value of α as function of time for $b = 21$ s.

A limit case is $\alpha = 1.0$, i.e. the conductivity cell exhibits no immediate response to a temperature change. Comparing (7.2) and (7.7) it follows that for $\alpha = 1$

$$C_c = -\gamma T_c \quad (7.11)$$

For gradients in temperature small enough, the resulting change in salinity is given by $dS \propto C_C + \gamma T_C$, showing that the methods for temperature correction and conductivity correction are equivalent for $\alpha = 1$. It is therefore expected that from (7.10), the relaxation time in the temperature correction model would be 4.14 s, which is close to the 3.65 seconds found before.

7.2.4 Correction of Glider CTD Data Set

Having looked at the procedure to correct for thermal inertia in detail (one profile) we now describe the processing of the complete glider CTD data set. For this purpose, the method described by Lueck (1990) is adopted.

The example profile used in the previous subsection showed that optimal values were $\alpha = 0.23$ and $b = 18$ s. In addition, it seems there is a line in $\alpha - b$ space for which the $S - \theta$ curve seems to collapse onto a unique curve. The question not addressed so far is do α and b vary with time? To answer that question, 16 profiles have been selected to cover the whole deployment period, provided that the profiles were deep profiles (down to 1000 m). A search algorithm was developed to find both α and b . The results showed that α varied significantly in time, but that values for b found were mostly within 20 and 22 seconds. (In the previous section we found with a different algorithm that $b = 18$ s. However, Figure 7.5 also indicates that an α can be found for $b = 21$ s for an equally good correction.) Repeating the search algorithm for a fixed value of $b = 21$ s, the optimal values for α are shown as function of time in Figure 7.9. The figure shows that α increases with time from values as low as 0.12 to about 0.5. For practical purposes, a second order polynomial is fitted through the data, which is used to set α when correcting any other profile gathered by the glider.

Why α increases as shown in Figure 7.9 is not clear. It may be related to the speed of the glider. As mentioned before, a slower through flow rate causes α to increase. Due to technical problems with the buoyancy pump the glider did slow down over time. Investigating the time dependency of α is left for future work.

7.2.5 Sensor Drift

As the conductivity measurement is based on measuring the electrical resistance of a sample volume, contamination can occur that affects the effectiveness of the electrodes or the sample volume. In the data this would appear as a sudden or gradual change of water characteristics in $S - \theta$ space that could be expected to be constant. In order to get an impression of the drift, a number of 10 profiles are represented in the $S - \theta$ diagram in Figure 7.10. The colour indicates the date in 2008. The data collected at depth (corresponding to the lower left part of the graph) seem consistent, although a close inspection (bottom panel) suggests that there is a slight drift towards lower salinity. The question whether the drift is real or not is addressed in the next section.

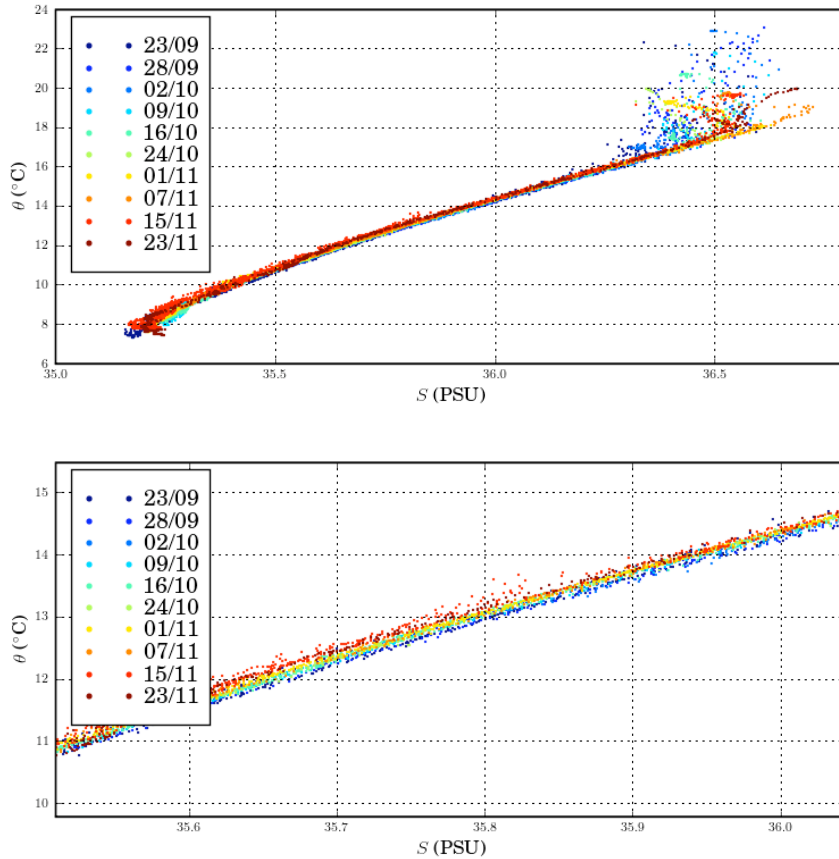


Figure 7.10 $S - \theta$ diagrams for various dates.

7.3 Comparison with Mooring Data

The glider trajectory was planned such that the glider would come close to the moorings EBH3, EBH4 and EBM1 of the RAPID array. Each of these moorings was equipped with one or more CTD sensors, fixed at a certain depth, Table 7.1. Selecting those profiles only when the glider is near one of the tabulated moorings, we find the number of encounters within 3 km to be 4 for EBH3, 15 for EBH4 and 3 for EBM1. As EBH4 has been visited most frequently and also has the most CTD sensors, the main focus will be on this mooring.

	EBH3 [m]	EBH4 [m]	EBM1 [m]
1	900	361	523
2	999	439	
3		539	
4		641	
5		744	
6		841	

Table 7.1 Depths of CTD sensors for the mooring EBH3, EBH4 and EBM1

To avoid cluttering of the graphs later on, we will take into account only data that were collected whilst within 1 km from the mooring, yielding 5 profiles with id's 50; 78; 82; 96; 104, covering about 2 weeks. Figure 7.11 shows the conductivity and temperature as function of depth (top two panels) and a $S - \theta$ diagram (bottom panel). The data from

the glider are indicated by solid lines, whereas the mooring data are represented by circles. The colours indicate the profile number.

From the profile data it can be seen that during the covered period a fair bit of variation is measured by the glider in both conductivity and temperature. At first glance, this variation corresponds to the variation observed by the mooring CTD's. The bottom panel shows the data in $S - \theta$ space for the moorings and the glider. The glider data have been corrected as explained above. It is seen that both observation platforms agree on the $S - \theta$ curve.

Taking a closer look at the same data (Figure 7.12) we see that for a given profile, the glider observes conductivity and temperature values that are in the same range as the mooring CTD's do. As was observed in the previous section from the glider data, the curves in $S - \theta$ space seem to shift to the left with time. Close inspection of the $S - \theta$ diagram in Figure 7.12 shows the same phenomenon in the mooring data, indicating that the effect is real and not caused by sensor drift in the glider's CTD sensor.

Completing the comparison by including the data of the other two moorings, we find the $S - \theta$ diagrams as shown in Figure 7.13 (all data) and 7.14 (zoomed in). The high level of detail of Figure 7.14 reveals that the glider data also agree well with the data from moorings EBH3 and EBM1.

7.3.1 Spatial Correlation Between Glider and Mooring Data

In this section the spatial correlation between the data obtained with the glider and those from the mooring is investigated. To that end, CTD data of the glider that correspond in both time and depth with the CTD data of a given CTD instrument on a mooring are compared. The procedure followed is that glider data are split into single profiles, either an up or a down cast. Both pressure data of the mooring and glider are subsampled at 1 Hz by linear interpolation. The time of crossing is then defined as the time for which the pressure difference is minimal. Salinity and potential temperature are then evaluated for the time of crossing also by linear interpolation. Subsequently, the difference of mooring and glider salinity and potential temperature is binned with respect to the distance between the mooring and glider position, with bin size of 2 km.

The number of observations per bin for each of the mooring instruments is shown in Figure 7.15. It is seen that the instruments attached to mooring EHB4 have roughly 40 or more observations per bin within the 10 km range. The other two moorings, EHB3 and EBM1, have significantly fewer observations nearby.

The mean of the differences in temperature and salinity per bin are shown in Figure 7.16. It is seen (in the bottom panel) that for short distances the mean temperature difference is for most moorings smaller than about 0.02 °C and that the mean difference fluctuates around 0 within 0.05°C. The exception is mooring EBM1, that data of which should not be considered representative due to the limited number of data points. The mean differences observed in salinity (top panel) appear hardly to vary with distance, but show a systematic offset depending on the mooring CTD. Moorings EBH3, EBH4 5,6 seem to agree, whereas other moorings have their own offset. This suggests that a slight correction to the conductivity measured by the glider needs to be applied. The rms values of the differences in temperature and salinity per bin are shown in Figure 7.17.

The main cause of these differences is the small scale temporal and spatial variability due to internal waves.

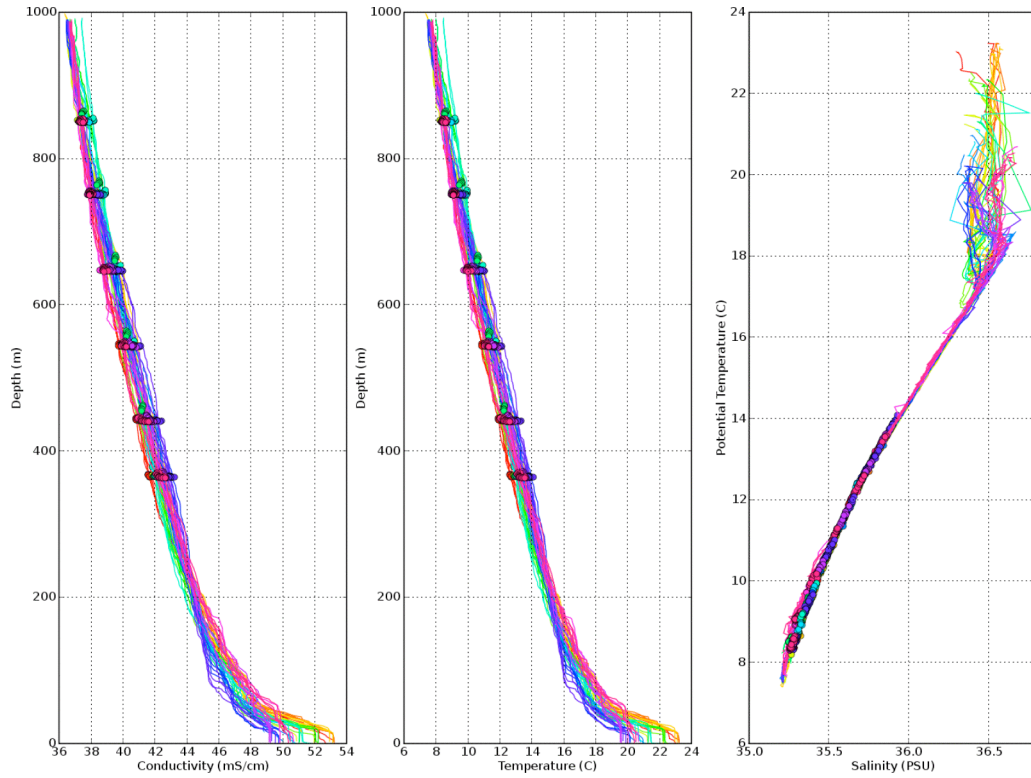


Figure 7.11 Conductivity, temperature and $S - \theta$ diagrams for mooring EBH4 compared with glider data.

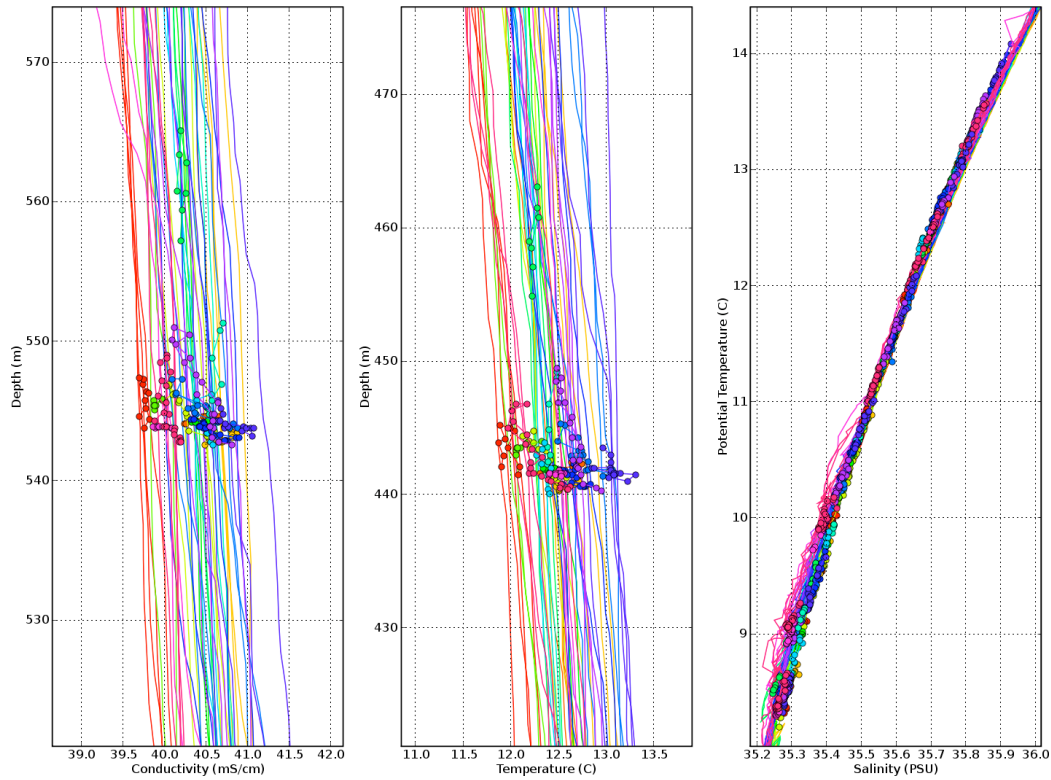


Figure 7.12 Conductivity, temperature and $S - \theta$ diagrams for mooring EBH4 compared with glider data, zoomed in.

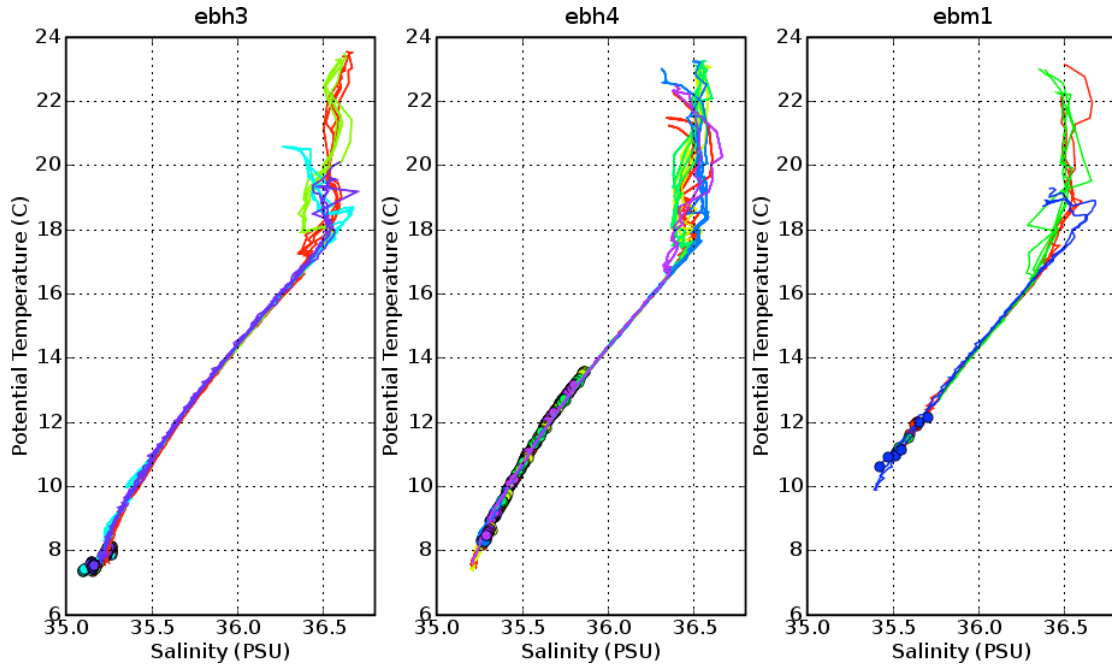


Figure 7.13 $S - \theta$ diagrams for all three moorings with glider data collected within 1000 m (3000 m for EBH3).

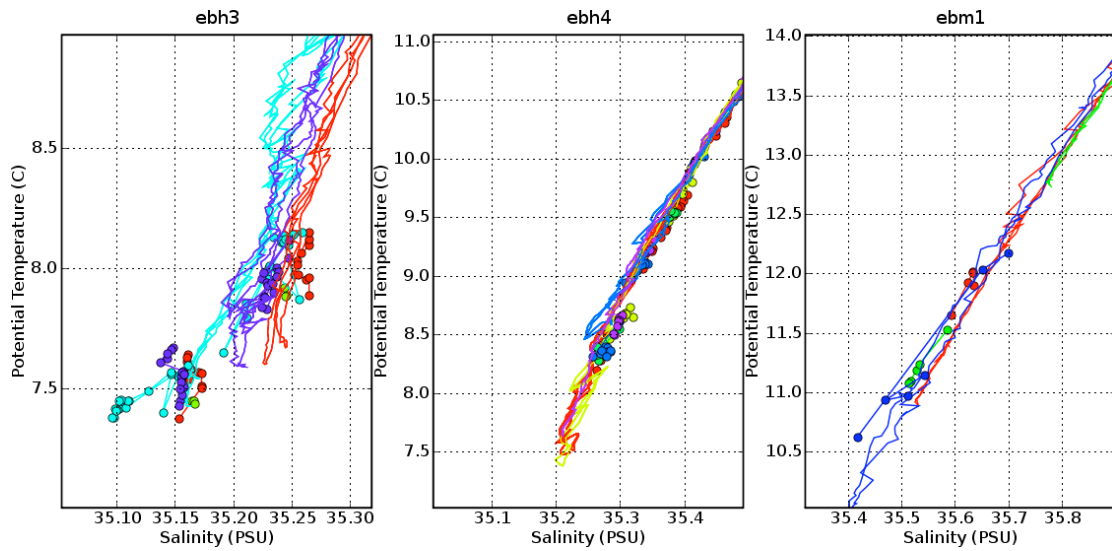


Figure 7.14 $S - \theta$ diagrams for all three moorings with glider data collected within 1000 m (3000 m for EBH3), zoomed in.

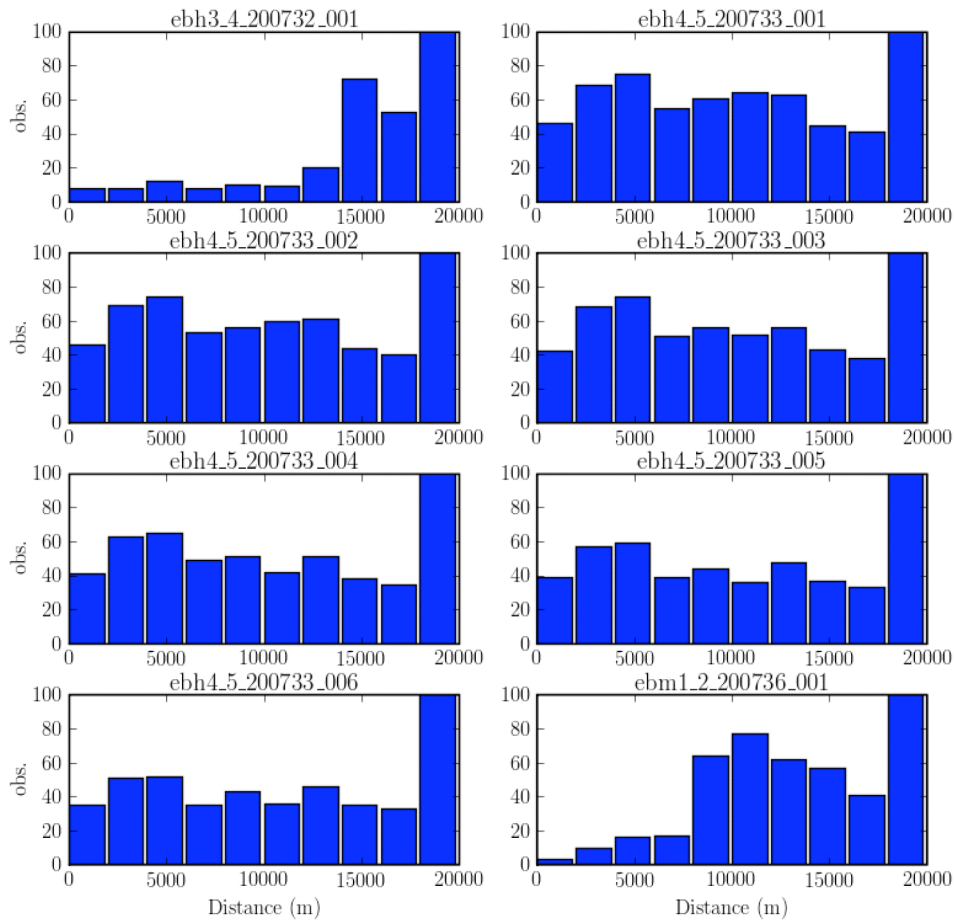


Figure 7.5 Histograms showing the number of observations per bin, for each of the moorings.

7.3.2 Calibration of Glider CTD

A careful inspection of the data in Figure 7.16 suggests that the difference between the corresponding (in time and depth) values for salinity as observed by the CTDs of mooring EBH4 and the glider, when the glider was within 2 km from the mooring, varies with depth.

Figure 7.18 shows the differences in salinity and temperature for the first distance bin (only data for which the distance between glider and mooring is less than 2 km). The potential temperature differences are within ± 0.02 °C and do not show a depth dependent behaviour. The accuracy of the CTD thermistor is about 0.002 °C. Taking into account the rather indirect way of comparing, the temperature performance is considered satisfactory.

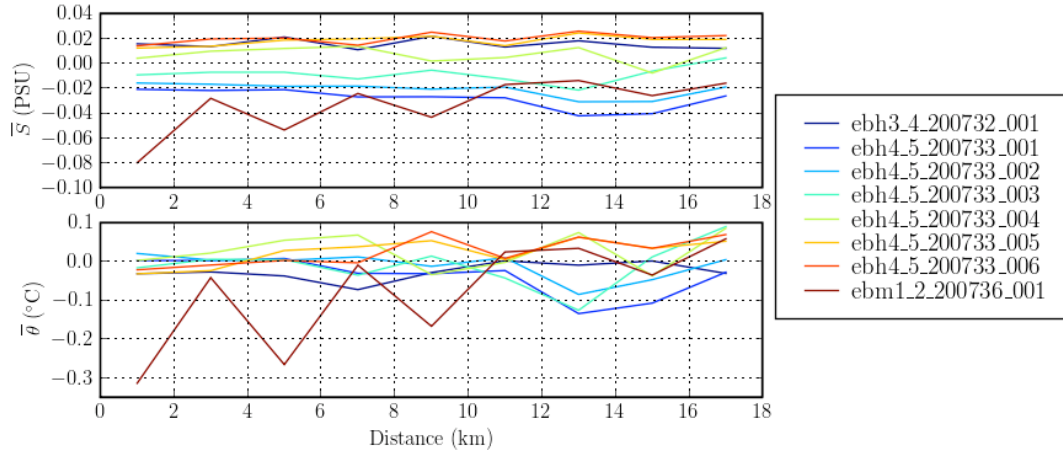


Figure 7.16 Mean of salinity (top panel) and potential temperature (bottom panel) difference of mooring and glider data as function of distance between glider and mooring. (Bin size is 2 km.)

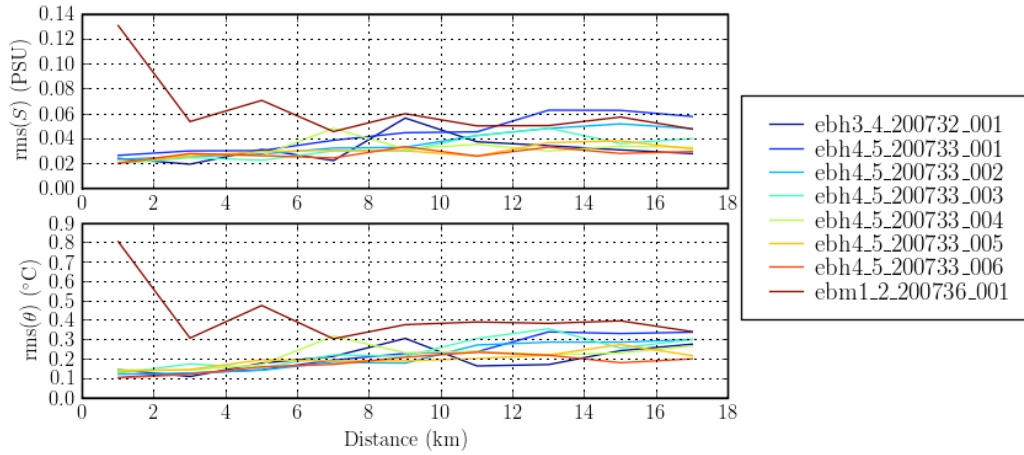


Figure 7.17 RMS values of salinity (top panel) and potential temperature (bottom panel) difference of mooring and glider data as function of distance between glider and mooring. (Bin size is 2 km.)

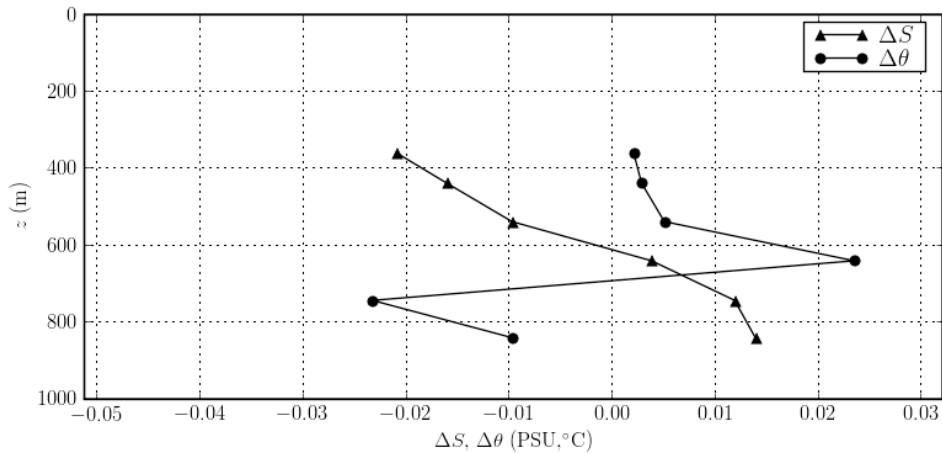


Figure 7.18 Variation of mean temperature and salinity differences between mooring data and glider data for the first 2 km bin as function of depth.

The averaged salinity differences, on the other hand, do show depth dependent behaviour. According to an Application Note by Seabird² the compression of the

conductivity cell and thus reducing the sampling volume, can induce an error of 0.028 mS/cm at 6800 dbars, or 0.004 mS/cm at 1000 dbar. The error observed is significantly larger. As conductivity increases with depth, and therefore it is difficult to distinguish between a possible combined effect of pressure and an offset CTD calibration parameters, the raw conductivity is calibrated by applying a slope and an offset

$$C = c_a C_{raw} + c_b \quad (7.12)$$

where c_a and c_b are the slope and offset calibration coefficients, respectively. By trial and error, the values found for the calibration coefficients are $c_a = 1 - 9.36 \times 10^{-3}$ and $c_b = 0.03683$ mS/cm.

Using the calibrated CTD data, the rms and average difference plots for salinity and potential temperature are shown in Figures 7.19 and 7.20. As to be expected, the potential temperature data have not changed noticeably. The rms values for salinity have also not changed noticeably, reinforcing the suggestion that the magnitude of the rms values is determined by internal waves. The result of applying the calibration factors is that the average difference in salinity for mooring EBH4 and glider data is +/- 0.01 PSU and no depth dependent behaviour is present.

Time series for both the mooring data and the glider data are compared in Figures 7.21 and 7.22 for salinity and potential temperature, respectively. The top panels show all data gathered during the deployment. It is seen that the variability shown in the mooring data is matched well by the glider data. Provided that the glider is close enough to the mooring, the glider data represent the mooring data well for time scales of the order of a day or larger.

The mooring CTDs sample at 15 or 30 minute intervals, which allow for resolving the internal tide and internal waves with frequencies of 1 hour or lower. Zooming in, (bottom panels) this is confirmed by the presence of fluctuations of the order of twice a day (internal tides) and higher frequency fluctuations (internal waves). As the glider travels along a saw-tooth shaped trajectory (in the vertical plane), it can only sample salinity or temperature at a specific depth every 2 hours (on average), which should be enough to resolve the internal semi-diurnal tides. Indeed, the internal tides seem present in the glider data as well.

Future work may well focus on the studying internal waves from glider data. The high sampling rates (once per 20 seconds) allow this, but the fact that the glider moves in the horizontal and vertical plane makes the interpretation of the data not straight-forward.

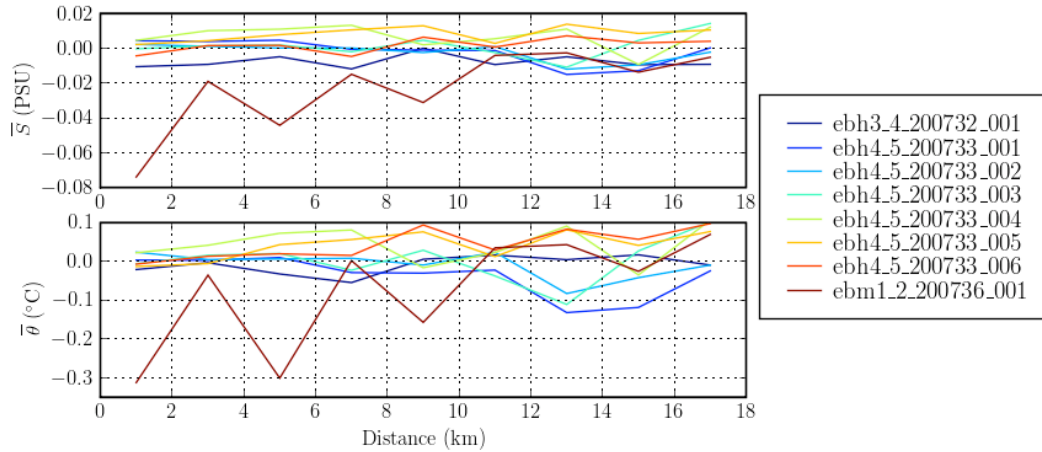


Figure 7.19 Mean of salinity (top panel) and potential temperature (bottom panel) difference of mooring and calibrated glider data as function of distance between glider and mooring. (Bin size is 2 km.)

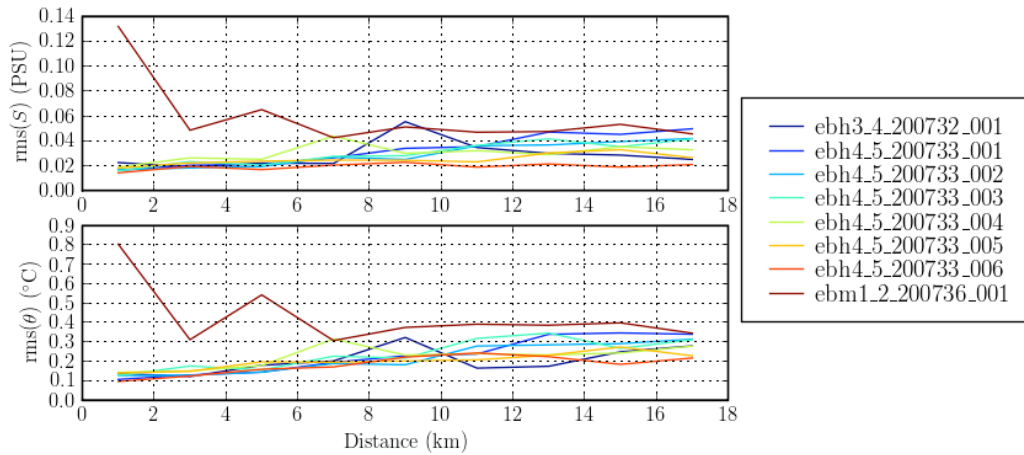


Figure 7.20 RMS values of salinity (top panel) and potential temperature (bottom panel) difference of mooring and calibrated glider data as function of distance between glider and mooring. (Bin size is 2 km.)

7.4 Conclusions

An analysis of the CTD data of the glider *Bellamite* used in the Rapid2008 experiment shows that the temperature data lag the conductivity data. This effect is attributed to thermal inertia. A simple filter to adjust the temperature, used in the salinity calculation, is used to correct for this effect. The time scale involved is about 4 seconds. A more complex filter is due to Lueck (1990), which adjusts the conductivity in relation to temperature changes. Here it is assumed that the conductivity cell responds immediately to temperature changes only partially, followed by an exponential decaying adjustment with time. It is shown that if no immediate response occurs, both methods are identical. A detailed analysis of a single profile showed that $\alpha = 0.23$ (i.e. 77% of the conductivity change is immediate) and the relaxation time b is 18 s.

A search algorithm was developed to find α and b for a number of profiles representing the whole deployment. It was found that $b \approx 21$ s (slightly higher than the value found from the single profile analysis) and α increased with time. For this particular data set, a second order polynomial as function of time was fitted to interpolate α for profiles not

used in the calibration. Further investigation is needed to understand why α increases with time. It could be related to the speed of the glider and/or bio-fouling of the CTD duct.

A comparison was made with CTD data from moorings EBH3, EBH4 and EBM1 from the RAPID array. Limiting the comparison for glider data that were collected within 1000 m of the mooring (3000 m for EBH3), it follows that the conductivity and temperature variation as measured by the glider were also observed by the mooring EBH4. The resulting $S - \theta$ diagrams are slightly different for each mooring, but compare well with the corresponding $S - \theta$ diagrams as observed by the glider.

Based on the comparison with mooring data of EBH4 it appeared that the averaged difference between the salinity from the mooring CTDs and the glider CTD, when the glider was with 2 km from the mooring, varied with depth. This systematic variation was removed by applying a multiplication factor and an offset to the raw conductivity data of 0.99664 and 0.0368 mS/cm, respectively.

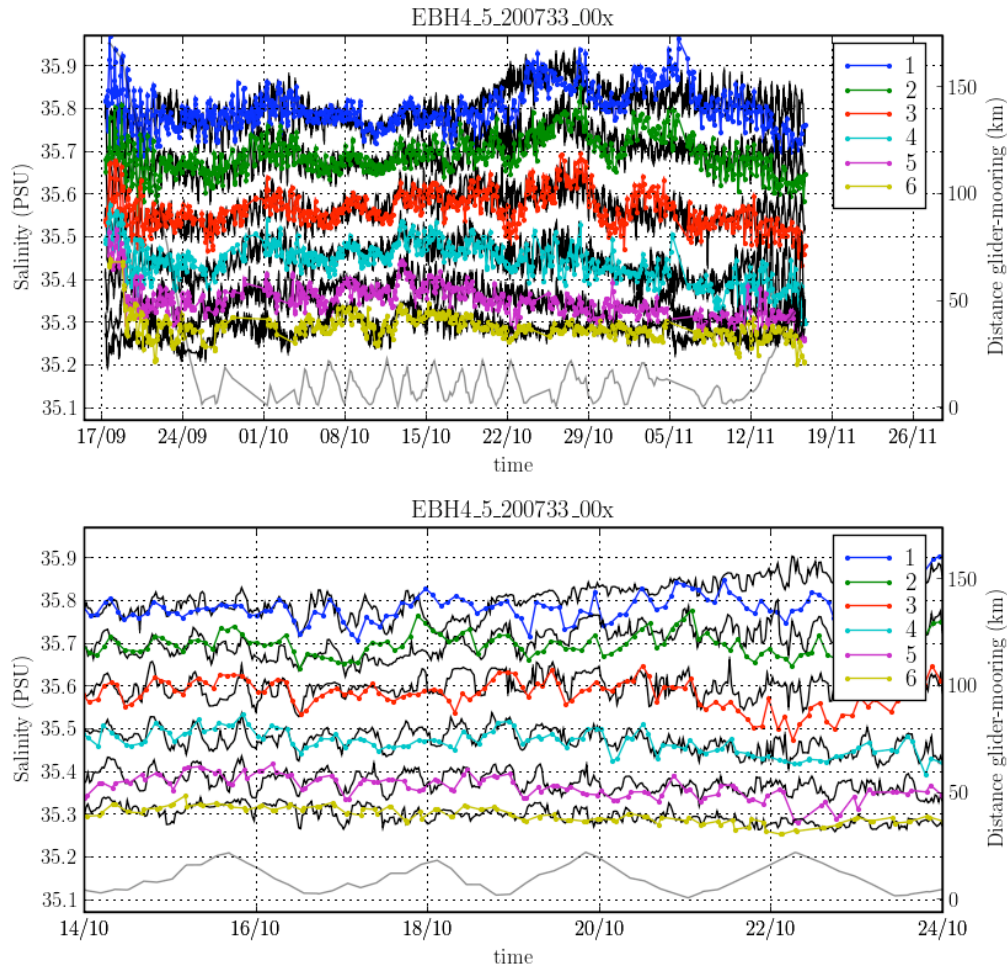


Figure 7.21 Time series of salinity for mooring data (black) and glider data (color) at different (mooring) instrument depths. The gray line represents the distance between mooring and glider (right-hand side axis). Top panel: all data, bottom panel: a 10 day period. (The legend number refers to \times in EBH4 5 200733 00x.)

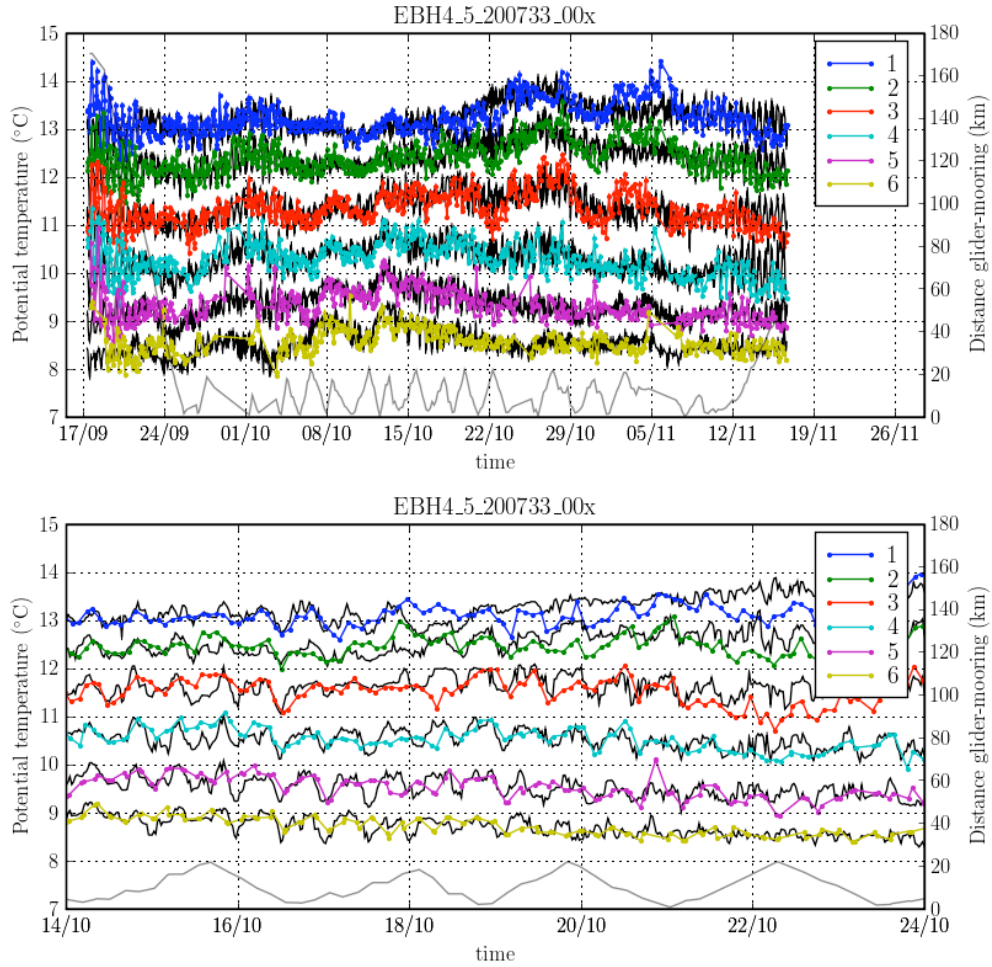


Figure 7.22 Time series of potential temperature for mooring data (black) and glider data (color) at different (mooring) instrument depths. The gray line represents the distance between mooring and glider (right-hand side axis). Top panel: all data, bottom panel: a 10 day period. (The legend number refers to \times in EBH4 5 200733 00x.)

8 Comparison of the MOC Anomaly - *Bellamite*

Paul Wright

8.1 Introduction

The aim of this section is to continue from Merckelbach's comparison of the CTD measurements of the glider *Bellamite* with the MicroCAT data and directly compare the final gridded output dataset with that produced from the moored MicroCATs, and quantify the effect on the final MOC calculation.

8.2 Data Format

The raw data is downloaded from the glider in a large number of .sbd binary format files and is converted to ASCII and/or .mat format using software provided by Webb Research. The programs are located on the RAPID-MOC directory,

```
rpdmoc/rapid/data/glider/linux_programs
```

For Linux the command is:

```
ls bellamite-2008-*.sbd | dbd2asc -s | dba2_glider_data
```

This creates two files:

```
bellamite-2008_XX_X_XX_sbd_gld.m  
bellamite-20098_XX_X_XX_sbd_gld.dat
```

The MATLAB script assigns the variable names to the data. Merckelbach (2009) has worked on directly comparing the glider data with each MicroCAT that the glider came close to in time and space during the mission. From this he was able to calibrate the data and add corrections due to the rate of descent of the glider, hysteresis and her forward velocity. As expected it was discovered that the differences increased with distance from the MicroCATs, with 10 km being the point where the rms values start to exceed 0.2 °C for the temperature and 6 km where the rms values exceed 0.2 PSU for salinity. However, it was found that due to the trial nature of the *Bellamite's* deployment, restricting the data to less than 6 km reduces the quantity of the data by a very large amount. Therefore 20 km was chosen as a compromise, thus removing the deployment and recovery tracks. The corrected data produced by Merckelbach, *bellamite-rapid08-corrected-CTD.mat*, was used for the following comparison.

The data within a 20 km radius of the mooring EBH4 were then fitted to a 20 dbar pressure and 12-hourly time grid. This matches the gridded mooring dataset used by the RAPID-MOC project to quantify the strength and variability of the MOC. The gridding was carried out by binning the data into 20 dbar pressure levels and then averaging them over each 12-hour period.

The MATLAB script for the *Bellamite* gridding process is, *bellamite_data_processing.m*, which produces the file, *bellamite_gridded_data.mat*. The variables in upper case are the 10-second interpolated and gridded data, the lowercase matrices have been binned to the 12-hour time grid, *jd*. In this file glider the data is unfiltered and the effect of the tides is still evident. The gridded mooring data was 2-day low pass filtered to attempt to remove this

tidal signal. The first step was to run a loop to interpolate all the 50 levels of data with the NaNs removed by indexing. Then the data was run through a 2-day low pass filter, $(\text{auto_filt}(x, 2, 1/2))$ over the period that the glider was within 20 km of EBH4.

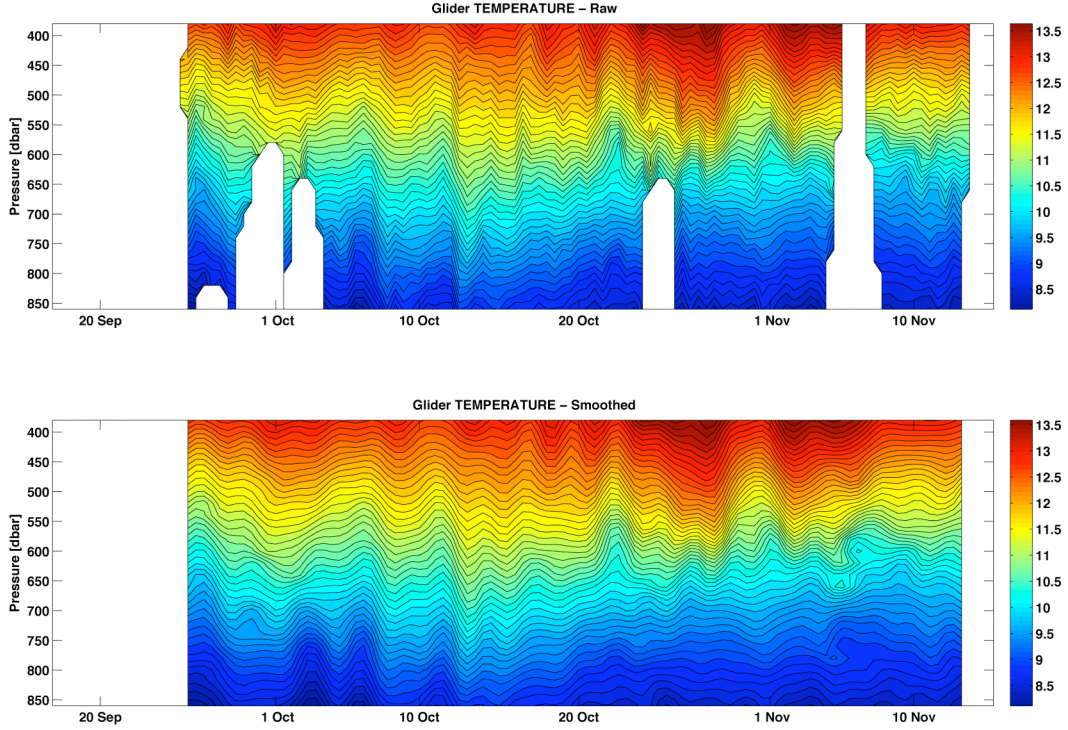


Figure 8.1 *A comparison between the raw gridded temperature dataset and the 20 km filtered unsmoothed glider data. The data gaps are due to the distance exceeding 20 km, the glider remaining surfaced and the glider not diving to the full depth*

8.3 Comparison of the MOC Anomaly

The MOC anomaly for the variability of the eastern boundary was carried out using the following relationship:

$$\Delta T(t) = \frac{1}{f} \int_{-z}^0 [\Delta \Phi(z, t) - \overline{\Delta \Phi(z)}] dz \quad (8.1)$$

where $\Delta T(t)$ is the net transport anomaly, $\Delta \Phi(z, t)$, the geopotential height anomaly, $\overline{\Delta \Phi(z)}$ is the mean geopotential height anomaly, $-z$ the reference depth and f the Coriolis factor (Pond and Pickard 1983 and Longworth 2007). The program that carries out the smoothing and comparison is:

```
rapid/data/glider/bellamite/glider_and_EBH4_MOC.m
```

There is a similarly named program that carries out the same function but compares the glider data to the eastern boundary merged data.

The merging of the eastern boundary mooring data deserves explanation. As basin-wide density gradients are used to compute the MOC, the ideal situation to monitor the temperature and salinity along the slope of the ocean floor to produce a boundary profile. This requires a series of moorings at various depths, from the offshore full

depth EB1 located at the base of the continental shelf at 5000m to the shallower EBH and EBM (mini) inshore moorings. There is an overlap in the depths that the moored MicroCATs are deployed, partly as a back up for lost moorings. This explains the reason that the 539 dbar MicroCAT on EBH4 is not included in the final merged profile (Fig. 8.2) as the 500 dbar one on EBM1 is closer inshore. Due to the upwelling and the proximity to the coast this area is heavily fished, which puts the moorings at risk. Unfortunately two of the mini moorings were lost during the 2007 – 2008 period, leaving a large gap in the data between the upper EBH4 MicroCAT and the one on the EBM6 mooring.

The profiles are then gridded by fitting a climatological relationship between the points. This means that while the profiles based on the mooring data have an excellent temporal resolution with a 30 minute sampling regime, the vertical depth resolution is poor with the profile only having eight data points between 120 and 860 dbar.

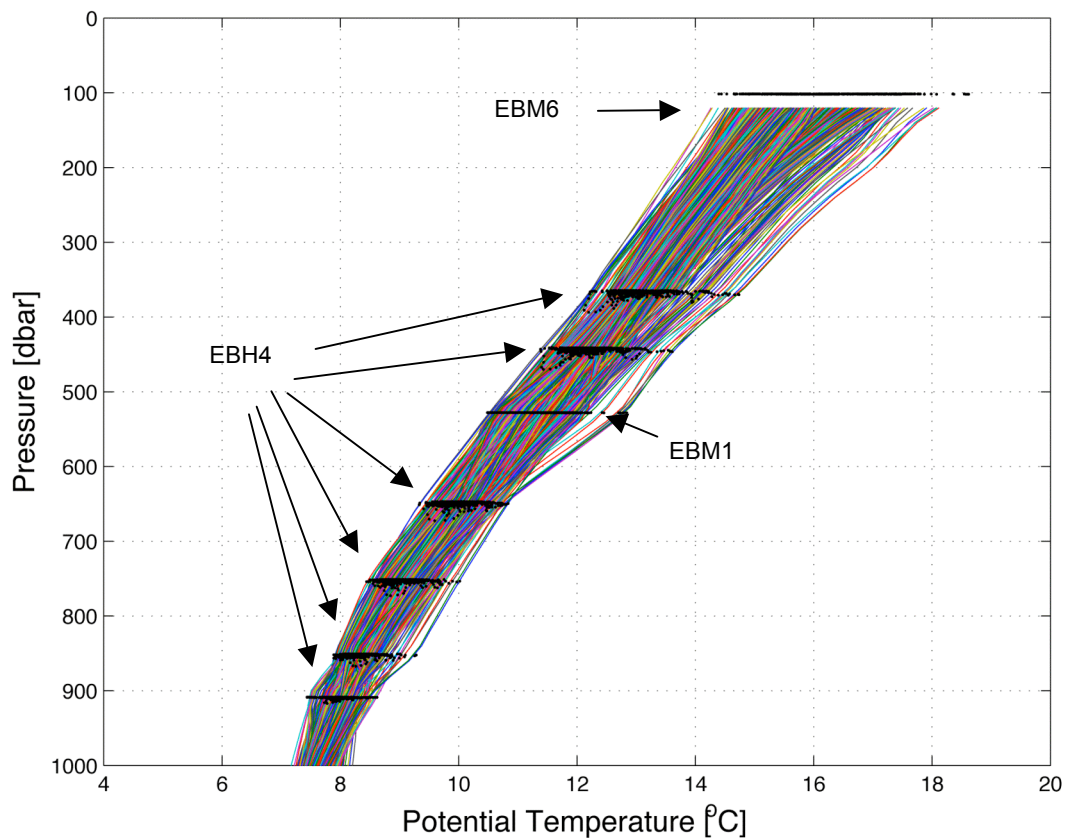


Figure 8.2 The merged profile as produced by the code `hydro_grid_merge.m` for merging the MicroCAT data for the moorings EBH4, EBM1 and EBM6.

Two comparisons were carried out, the first being a direct comparison with the profiles based solely on the mooring that the glider was in closest proximity to for the majority of the deployment, EBH4, with a depth range of 380 → 860 dbar. The second was based on the merged profiles of EBH4 with the inshore moorings EBM1 and EBM6. As these moorings were located at a greater distance from the glider it was expected that there will be less correlation between the datasets. As the current method of merging the mooring datasets cuts the time scale to a common period, which finishes on 27th Oct 2009, it is difficult to make a suitable comparison with the merged profiles for the full depth to 980 dbar. The way in which the mooring data are merged is currently being reviewed by the RAPID-MOC group.

Viewing the potential density profiles in Figure 8.3 it is possible to see some similarities in the contours, particularly when the glider is close to the mooring (around 10th October and 30th – 31st October. Some other times when the glider was in close proximity to the mooring coincide with some of the data gaps in the record. The whorl of high density water overlying lower density water during 5th November would appear to an artifact of the interpolation over one of these data gaps (Figure 8.1).

Figure 8.4a shows MOC anomaly due to the eastern boundary variability calculated from the glider data and the mooring data. It is apparent that the glider captures the MOC anomaly well, with some higher frequency variability evident, possibly due to the greater vertical resolution detecting some internal tides that the mooring does not. The correlation is very good as shown in Figure 8.4b and Table 8.1.

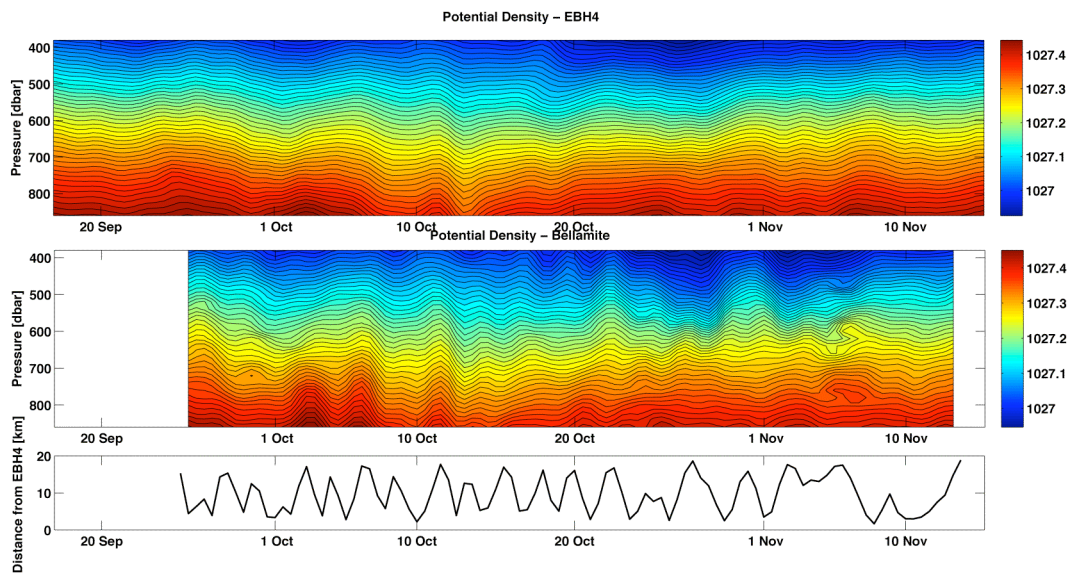


Figure 8.3 Comparison plot of the gridded and smoothed potential density profiles based on a) the mooring and b) the glider. The whorl visible on the 5th November, which apparently shows unstable temperature inversions is most likely an artifact of the interpolation over the data gap during that period (see Fig 10.1b)

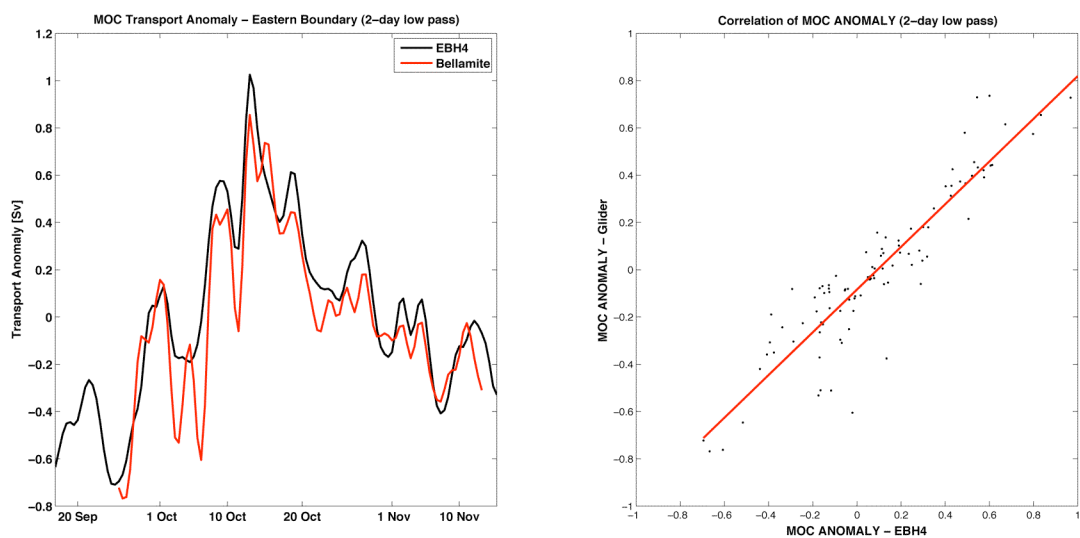


Figure 8.4 Comparison of the MOC anomaly for pressure range 380 → 860 dbar due to variability of the eastern boundary due to the mooring (black) and the glider (red).

The comparison of the glider and the merged profile of the three moorings is shown in Figures 8.5 and 8.6. This is over an extended depth range of 120 dbar to 860 dbar. As with the single mooring there is a general similarity but with the glider data highlighting a greater degree of vertical structure and variability than the mooring.

The correlation between the merged profile and the glider data is shown in Figure 8.6. While not as closely matched as the single moored data it does capture the general overall transport in a convincing manner. As noted earlier, the merging process between the various moorings is an approximation using the best available observations. It may well be that the glider can improve on these.

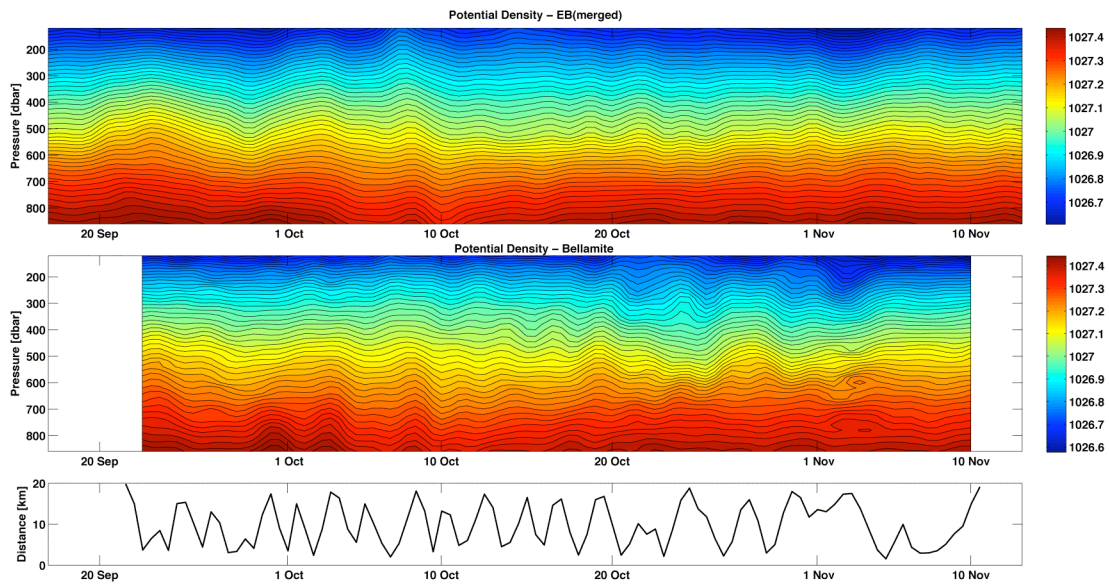


Figure 8.5 Comparison of gridded glider data with the merged eastern boundary profile.

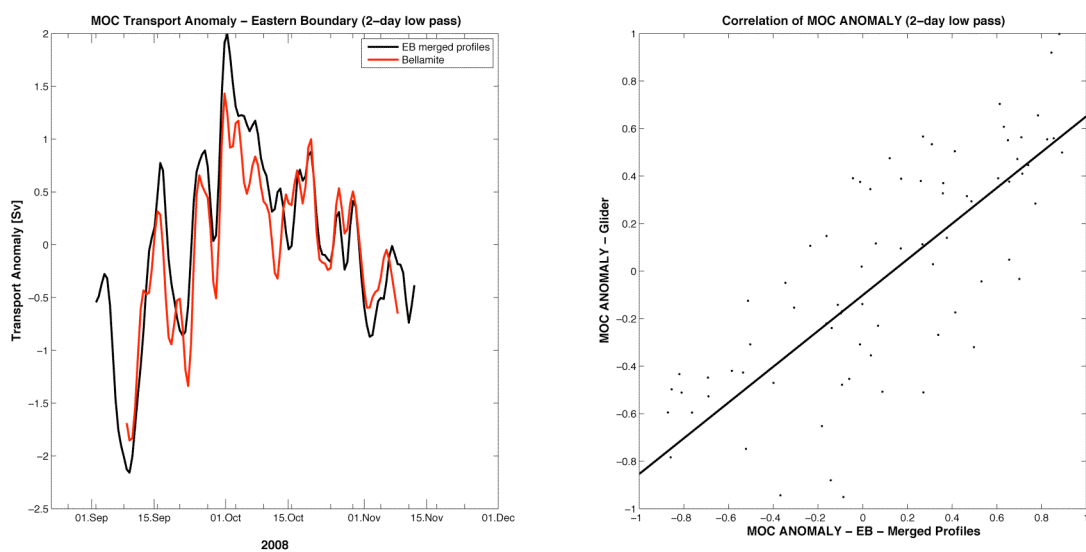


Figure 8.6 Correlation of the MOC anomaly for the merged eastern boundary profile and the glider data.

	EBH4 only (380 → 860 dbar)	Merged Eastern Boundary (120 → 860 dbar)
R ²	0.85	0.81
Norm of residuals	1.30	2.92
Std deviation of residuals	0.13	0.30

Table 8.1 Basic fitted statistics for the comparison of the MOC transport anomaly due to the Bellamite gridded and smoothed data with that due to the gridded and merged mooring data.

8.4 Tide Removal

In the above analysis, the tidal effects were simply removed by a 2-day low pass filter. It is suspected from careful observation of the potential density profiles that this may need to be refined and the tides removed by fitting harmonic functions instead. This is left for future work.

8.6 Summary

It seems to be clear that the increased vertical resolution of the glider data, at the slight expense of the temporal resolution should not affect the overall ability of the glider to replace or supplement the existing shallower moorings on the eastern boundary. The 12-hourly grid division used by the RAPID project contains enough data points to form a representative dataset. A problem is the horizontal distance from the mooring, restricting the data to 6 km as suggested by Merckelbach's work reduces the size of the dataset by a very large amount. The second glider, *Dynamite*, was kept within 4km of EBH4 to enable a more direct comparison.

9 The Second Deployment – *Dynamite*

Paul Wright

9.1 Introduction

The deployment of the new NOCS glider specially dedicated to the RAPID-WATCH program did not go quite as smoothly as the *Bellamite* mission. *Dynamite* is the newest generation Slocum electric glider and many of the problems with the older gliders have been ironed out. Notably different are the nose cone and tail fin arrangements. The new digifin is shorter and more sturdy than the previous gliders. The membrane in the nose cone has been redesigned to reduce the amount of air that has entered in the past. She also has updated software and a 1GB memory card which reduces the amount of data that may need to be deleted on long deployments.

Despite these improvements the glider still started to show evidence of software bugs early in the deployment and the buoyancy engine started causing problems approximately half-way through the mission and ultimately rendered the glider inoperative, and as such requiring emergency recovery on 21st July 2009.

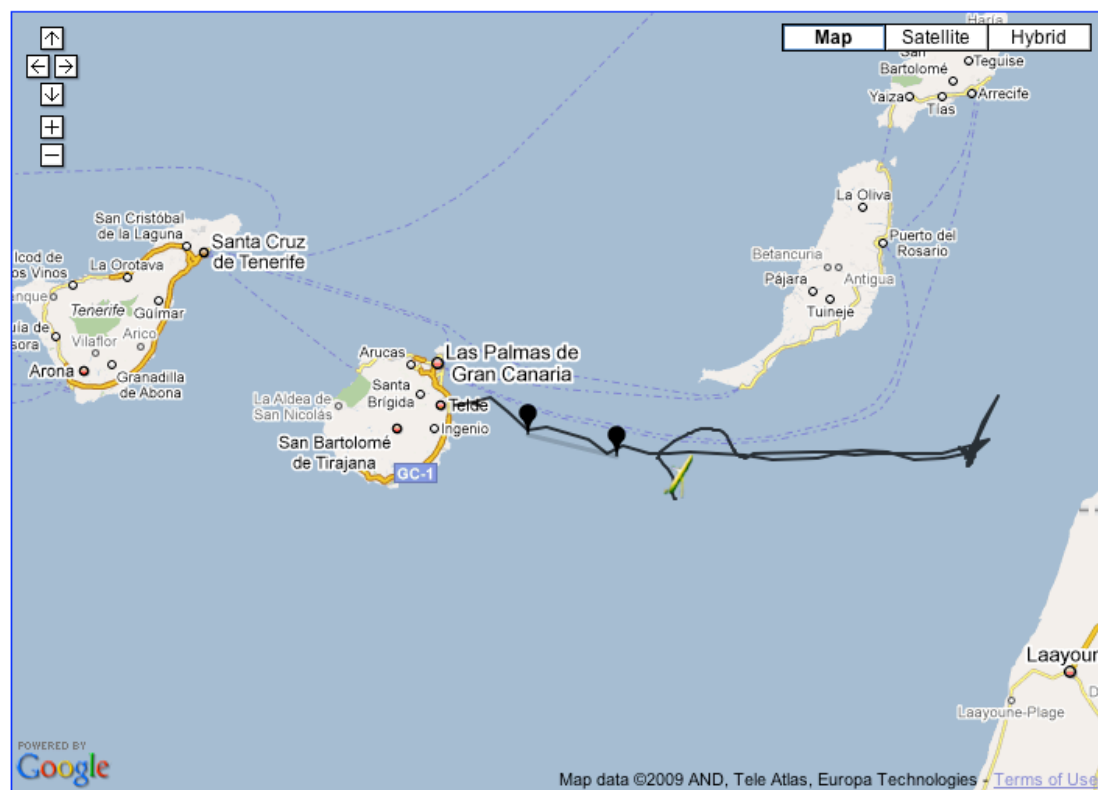


Figure 9.1 Chart of the deployment of the glider *Dynamite*.

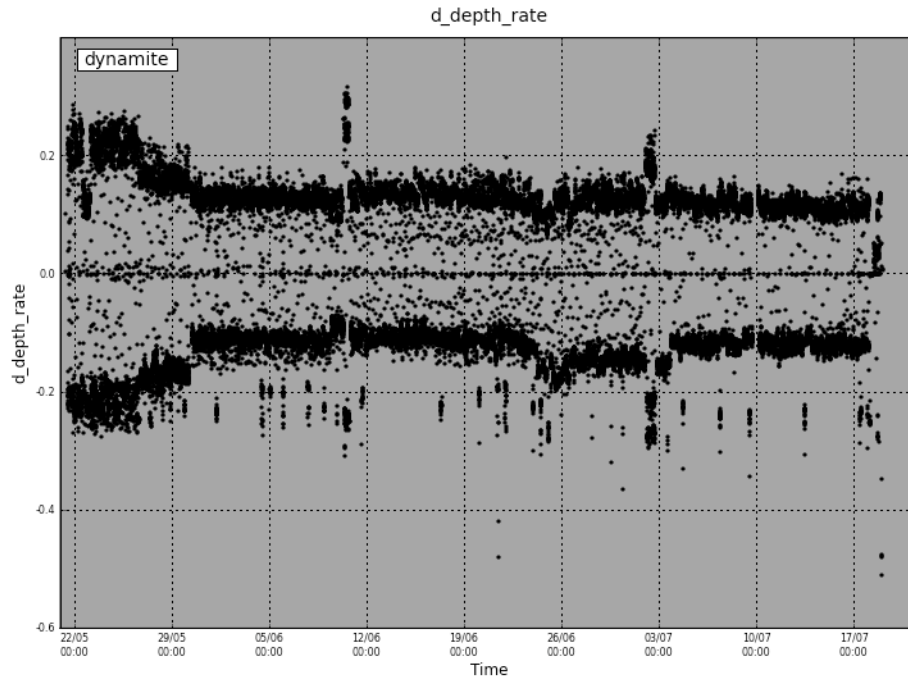


Figure 9.2 *The overall depth rate of the Dynamite mission.*

9.2 Mission Log

17th May – 20th May

Lucas Merckelbach and Paul Wright travelled to the Instituto Canario de Ciencias Marinas (ICCM) in the coastal village of Telde, Gran Canaria. There we met with Carlos Barrera Rodriguez, their chief engineer and liaison. As the glider was held up in customs we set about clearing space in the lab, establishing a wireless network, opening up the battery crates, weighing the batteries and generally getting ready.

Once the glider, named *Dynamite*, had arrived we proceeded to dismantle her and install the battery packs. Some ballasting had been carried out at NOCS but as the Lithium batteries must be shipped directly from the supplier this would only have been an approximation. ICCM needed to drain their water tank (Figure 5.7) to fix a small leak and to improve the pump arrangement. This potentially set us back by about half a day. Details of the ballasting and setting up of the glider can be found in chapter 5. This took longer than usual due to the training aspect of the work and changes in the software and hardware on the new glider. In particular the compass calibration took much longer than expected. However, given the sea state and the ship availability this was not a problem as we were unable to deploy until Thursday morning (21st) at the earliest.

21st May

We boarded the *RV Profesor Ignacio Lozano*, a converted fishing boat, before dawn and set up the laptop and FreeWave aerial. The RIB was lowered into the sea and the glider loaded aboard. Carlos and the RIB driver were briefed on procedures and in VHF contact at all times. The sea state was calm with a slight swell.

Once on station to the east of Telde in 400m of water the glider undertook a test dive

with a mooring buoy attached. Then we deployed her again without the tether and she again functioned correctly. She returned to the surface smoothly at her waypoint to the east, proving that she could navigate. We started the rapid.mi mission profile and she dived and headed towards two waypoints a few kilometers offshore where she would spend the day (28° 00.0'N -15° 18.10'W and 28° 00.0'N -15° 17.0'W) to perform complete yos and test whether the altimeter was functioning correctly. The idea was that with the FreeWave aerial on the roof of ICCM she would be close enough to download data and upload new commands without the use of Iridium (~ 4 km). This proved to be a bit optimistic and the communications were just barely in range and not really of sufficient reliability to fully download the dbd files. Also, the internet connection at ICCM was not stable enough to maintain the VNC connection to the dockserver at NOCS. This was much better at the hotel.

With the glider functioning as planned, we set her off to the waypoint SE of the island of Fuerteventura (27° 51.0'N 14° 48.0'W) with a yo depth of 980m and then on the location of the EBH4 mooring (27° 51.0'N 13° 32.39'W). The downcast pitch was changed to 15° to investigate its effect on the speed of the glider.

22nd May

As the downcast rate was now far too slow (<0.1m/s) the pitch was returned to 26°.

23rd May

Removed the Fuerteventura waypoint. It appears that when the new yo file that changed the profile to 4 yos was uploaded on to the glider it then reread the goto file. This caused the glider to return back to the waypoint off Fuerteventura! Something to be aware of for the future. Due to an unknown device error, that is suspected to be linked to the Iridium system, the profiles were returned to a double yo.

24th May

Glider support at Webb emailed regarding two device errors linked to the Iridium system.

26th May

Added waypoints to the NNE and SSW of EBH4 (27° 48.0'N -13° 45.0'W and 28° 02.0'N -13° 28.0'W) and changed the pitch to 22°.

28th May

Slowed the glider down as she is now on station by reducing the oil volume from +/- 270 cc to +/-150 cc.

30th May

Changed the initial waypoint behaviour in the goto file to avoid the glider returning to EBH4 every time a new yo file is uploaded.

31st May

The glider aborted during the night due to a conflict in the goto file when it was re-read. When the 4 waypoints were added, the number of waypoint commands was left as 1. This did not cause any problems when it was first uploaded on 26th May, however, when the initial waypoint behaviour was changed this caused problems, resulting in a series of aborts. The goto file was corrected and the glider continued on its mission. Later the glider did not dive to the full depth and only achieved 400m. It is improbable that this is due to the bathymetry. So it could be a problem with the altimeter.

1st June

The waypoints around EBH4 were changed to keep the glider within 4 km of the mooring to avoid distance related errors when comparing with the mooring data. (27° 48.84'N -13° 33.06'W and 27° 53.16'N -13° 31.74'W).

The dives have become irregular again, with the glider seeming to detect the bottom early and then proceed to ascend. It is suspected that this is due to the backscattering of the acoustic signal emitted by the altimeter from zoo-plankton. This has happened before on a number of previous deployments. To reduce the chances of this in future the minimum value of distance from the seabed was increased to 8m using the modified XML script: `sbd_num3_ToDock_set_var.xml`, in which the variable to be set was defined `put u_min_altimeter 8`.

5th June

On surfacing the glider was found to be 4 km too far to the east. This was rather strange and resulted in some discussion. Possibilities included:

- a) It had been picked up by someone/something. However, as the GPS position did not change during the log file and as the glider was later navigating correctly this was deemed to be rather unlikely.
- b) Advection by the tide. For some reason the glider had performed 3 yos rather than 2, and so had no GPS for 12 hours. Therefore this is a possible cause.
- c) A problem with the tcm3 compass. As the waypoints are close together and there are frequent turns (many underwater) it is possible that a heading error could cause a navigation problem. As this never happened again it is unlikely.

The odd number of yos was a bit of a concern. The thinking was that as they tended to follow a 'timeout', i.e. where the glider surfaces as it has not connected with the dockserver for 12 hours, it was a software 'bug'.

9th June

As part on ongoing experiments with the glider model, the oil volume was increased to +/- 300 cc and the pitch changed to 30° to speed up the glider.

10th June

Oil volume changed to +/- 100 cc and the pitch to 26° to slow it back down again.

16th June

Pitch increased to 28°.

25th June

Due to unknown problems with the buoyancy engine the oil volume for the downcast was increased by 50 cc. This was the beginning of the problems with the buoyancy engine.

26th June

As the yos were not quite symmetrical the oil volumes were adjusted to + 75cc on the ascent and -150cc on the descent.

29th June

There was some discussion on the recent changes to the buoyancy engine behaviour, the ideas that there was about 15 cc of air in the system due to ingress, dissolved in the external bladder or an oil leak were considered. The difference between the target and actual oil volume appears to have increased. That the problem appears to have stabilized would seem to discount the oil leak option. Lucas started to investigate the vacuum inside the glider and noticed a sharp decrease on the 21st June. Although the reason is not clear.

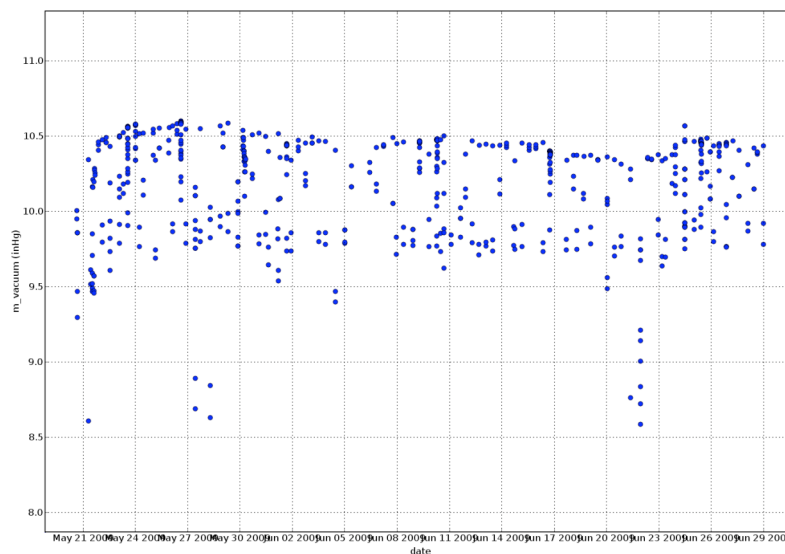


Figure 9.3 Measured vacuum from 21st May to 29 June. Note the big changes on 21st June and 28 May.

1st July

As a change of speed was requested for the model, the oil volume was changed to +225cc on the ascent and -300cc on the descent. There is now some concern that the energy consumption rate is too high (Fig 9.4).

The voltage under load appears to have dropped from about 11.8V to 11.5V. Doing a rough comparison with previous deployments that probably means we are, at 40 days, half way through this deployment. This is less than expected. Therefore at this point it

is useful to check the energy consumption estimates and see if there is anything we can do to lengthen the mission.

The lithium batteries should have a capacity of about 13.5MJ if we use 80% of that in 80 days then the average power is

$$P = 0.8 \times 13.5 \times 10^6 / (80 \times 86400) = \underline{1.5 \text{ W}}.$$

(Two assumptions: Gwyn's estimate of 13.5MJ is probably reasonable, but the 80% is an educated guess).

Currently the glider is doing about 6 yos a day with a total volume change of 125cc the propulsion energy for each yo is (volume x pressure)

$$E = pV = 2.25 \times 10^{-4} \text{ m}^3 \times 1000 \text{ dbar} \times 1 \times 10^4 \text{ Pa/dbar} = \underline{2250 \text{ J}}.$$

So, assuming an efficiency of 50%, the average power is

$$P = E/t = 2 \times 2250 / (4 \times 3600) = \underline{0.32 \text{ W}}.$$

This suggests that the glider is using about 1.2 W on everything else. This could be checked against the spreadsheet that Webb have provided (Appendix G).

A number of other suggestions were made to try to reduce power consumption:

- It should be possible to reduce the CTD sampling rate from once every 4 seconds to once per 8 seconds. (Following the production of Lucas's CTD report (see Chapter 7) it was considered a good idea to collect a few profiles with the glider at maximum speed on the 4 second sampling to try and understand why the response changed during the last mission - was it a speed effect or fouling of the CTD duct?)
- As the glider is close to the 1000m isobath, it was suggested that it may be an energy saving solution to have the altimeter on only below a specified depth, say 800m. Unfortunately, it was found not to be possible to set to set the altimeter to anything other than on/off. So this was considered too risky as the glider has wandered off course once and *Bellamite* grounded on the previous deployment.
- Fixing the battery position instead of the pitch, thus the battery only moves at the turning points rather than moving to adjust the pitch throughout the up and downcasts.

2nd July

The glider was slowed down again to conserve energy and additionally we experimented with fixing the pitch battery position rather than the pitch angle. Thus as a first estimate the battery was set to +0.75° on descent and -0.20° on the ascent.

3rd July

The ascent position was tweaked (to position = 0.0°) to make the yos more symmetrical.

12th July

The CTD sampling rate was changed from an 8 second interval to a 24 second interval to see the effect (if any) on the power consumption.

13th July

An email was sent to Glider support at Webb concerning the changes in the behaviour of the buoyancy engine and the increased energy consumption.

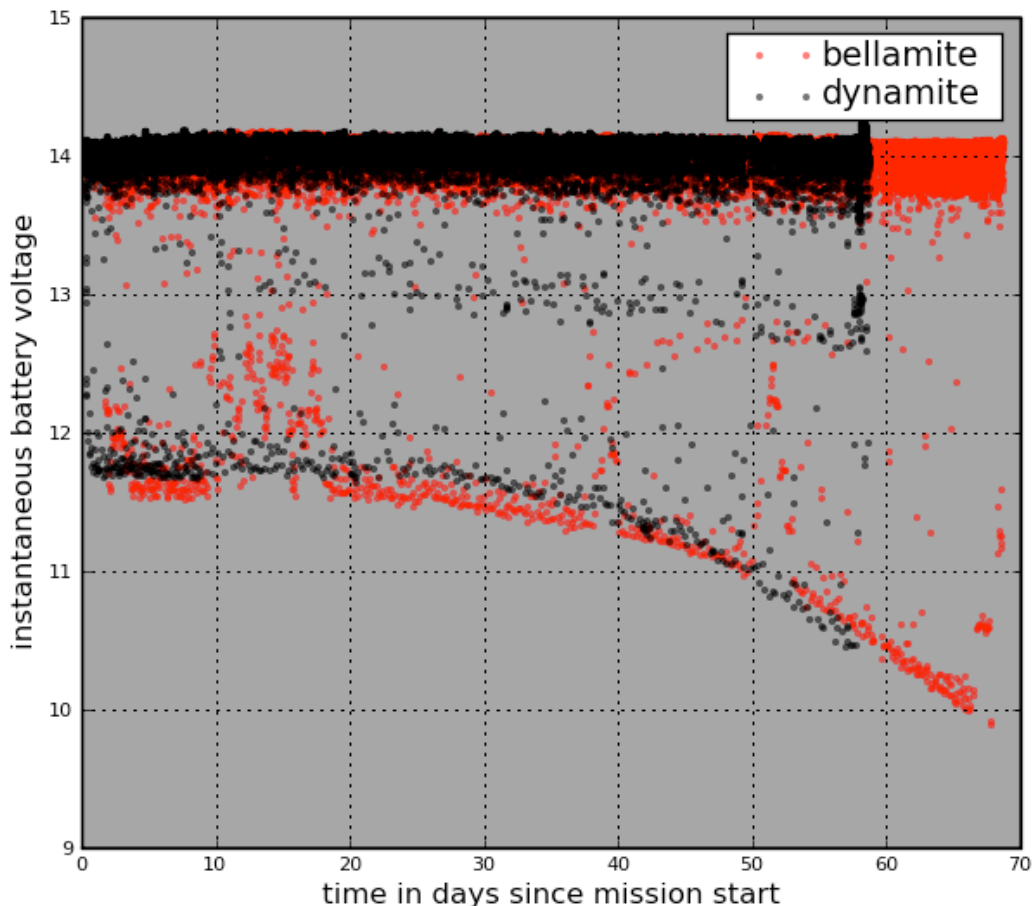


Figure 9.4 Plot to show how Dynamite's batteries depleted at a faster rate than Bellamite's.

14th July

The waypoints were removed and a new one off Fuerteventura was added to send the glider back to base. (27° 50.0'N -14° 20.0'W).

16th – 17th July

The new waypoint file containing the waypoint off Gran Canaria (27° 54.2'N -15° 06.8'W) failed to upload. This lack of destination is the likely cause of the glider remaining on the surface throughout the night. Why the file failed to upload until David manually uploaded the following morning is not known. The XML script was changed by David late Thursday evening and later checked by Paul. The glider did not make contact again with the dockserver for over 24 hrs until 21:16 GMT Friday evening

(segment 00570024). Despite being on the surface and continuously connecting with the dockserver throughout Friday night (a bad time since all staff were away from their computers or asleep) the script still failed to upload and remained in the to-glider directory.

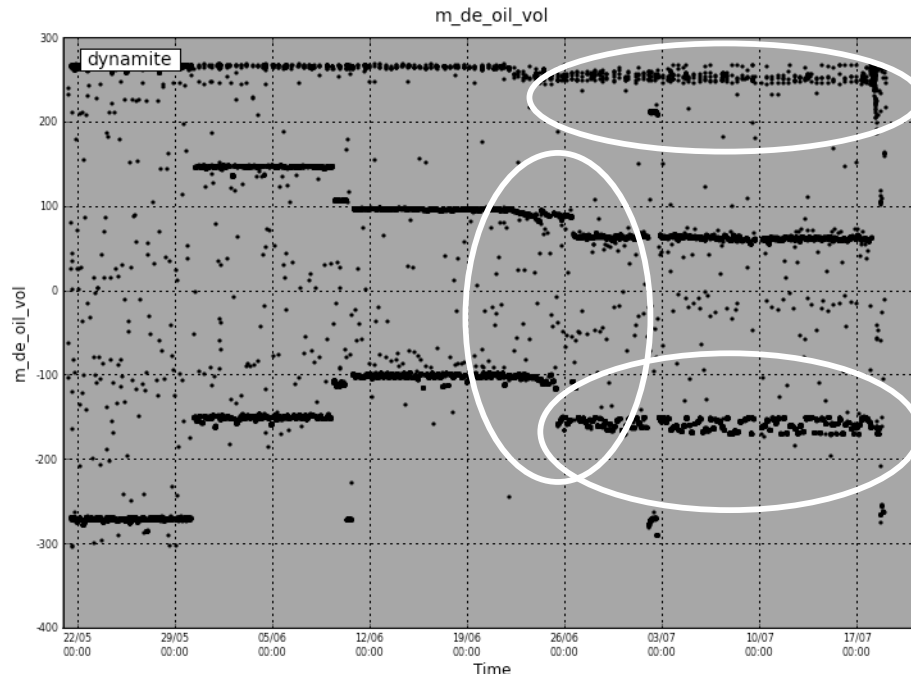


Figure 9.5 The oil volume for the Dynamite deployment. Note a) the sudden change 21st - 25th June and b) the spreading of the measured volume when the glider is on the surface (270cc) and diving (-150cc).

18th July

In the morning David was the first to notice that *Dynamite* had been on the surface and calling in every 15 min or so during the night. He realized that the new goto file had not been uploaded so did that manually and resequenced the mission. Afterwards he noticed that the oil volume had behaved very strangely (Fig. 9.6). It was unsure whether the glider was trying to dive while this happened, the pitch battery position did not change, so it was not clear what the sequence of actions was. Also battery voltage was low suggesting the glider was using a lot of energy.

After the goto file had been uploaded it aborted twice with 'same depth'. As no sbd files had been downloaded it was not immediately clear what depth that was - but it can't have been that deep due to the time periods involved. Therefore it looked like there was a problem with the pump

During the day the glider aborted again due to 'same depth'. Then at 16:20 GMT the glider aborted due to 'leak'. From this moment onwards things got a bit difficult as we were not certain that there actually was a leak as the leak detect voltage remained as 2.5V except in a very few readings, but in any case the glider would not dive for a long enough time anyway. The decision was made that the glider be left on the surface and a XML script was edited and run to tell the glider to callback every 110 minutes, thus reducing the Iridium costs and the power consumption. As the vacuum was still intact the glider's integrity was still stable and she was not sinking. However, the weather had been

consistently windy with a suspected heavy sea running. The other main point to note was that the oil volume was constantly going beyond the deadband (error margins for measurements) and not remaining stable. Thus it was hypothesized that the valve that restricts the oil flowing from the nose bladder to the internal reservoir had stuck open, causing the oil pump to run almost continuously. In order to reduce energy consumption, the deadband was set to 90cc.

An email was sent to Carlos in Gran Canaria requesting a boat, from either Gran Canaria or Fuerteventura, and a possible recovery. This was not received until Sunday evening.

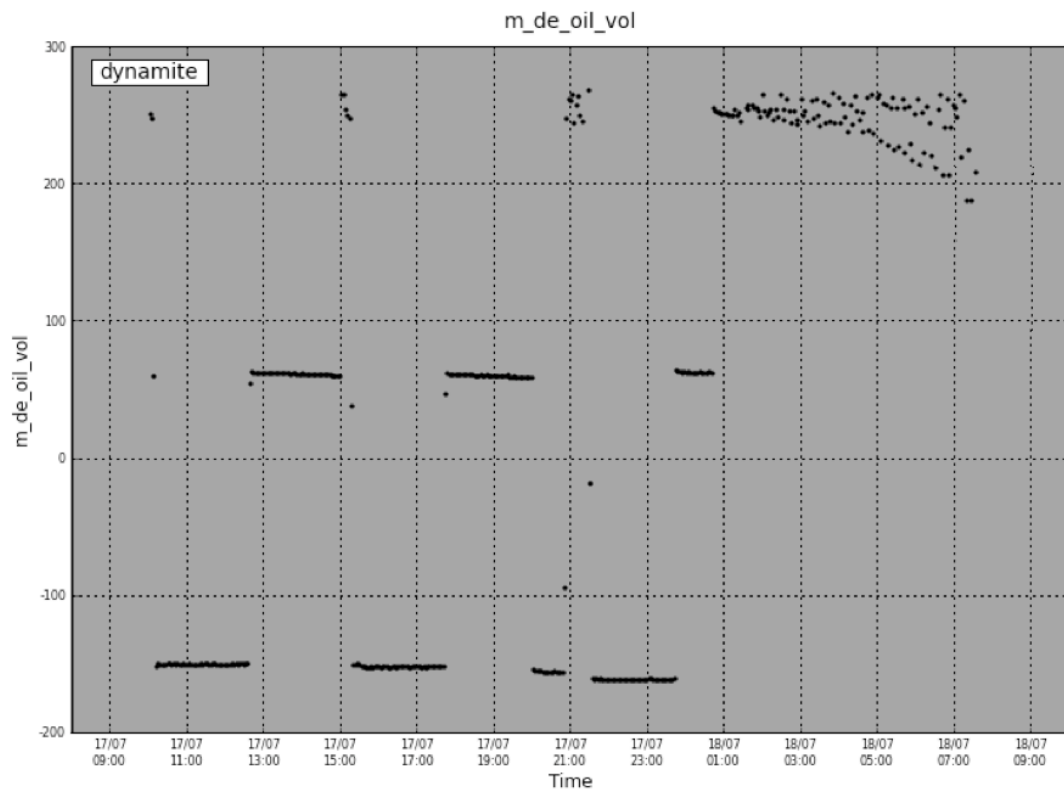


Figure 9.6 The oil volume from 17 July to 18th July. Note the large amount of oil present throughout the night, which seems to show signs of decreasing, which may indicate the glider was attempting to dive?

21st July

Carlos decided that due to the rough conditions a recovery from the ICCM's research ship would have been rather hazardous, and contacted the island's Search and Rescue base. As the glider is roughly the size and mass of a human they agreed to recover it as a training mission. Additionally they work closely with ICCM and they have a reciprocal agreement. The crew was briefed about the glider and any possible hazards, especially regarding the lithium batteries. Within a few hours the spotter plane had located *Dynamite* and the helicopter lowered a rescue diver into the sea with a stretcher to winch it aboard.



Figure 9.7 *The recovery of the glider Dynamite. (Photo courtesy of the Gran Canaria Search and Rescue team)*

24th July

A general email from Ben Allsop at Webb Research, which was subsequently confirmed to be related to the *Dynamite* oil pump problem.

Hello Deep/1000m glider users.

A logic fault has been identified in the software control of the thermal valve in the 1000 meter pump. The fault can cause the position of the valve to not be properly sensed. A software enhancement should be implemented and available by early next week. If any users have imminent deployments please contact Glidersupport@webbresearch.com.

For any users who presently have 1000m gliders in the water please add the following sensors to your sbdlist.dat and contact glidersupport for further instructions.

m_de_oil_vol
c_thermal_valve
m_thermal_valve

Regards,

Ben Allsup

9.3 Summary

As outlined in the Mission Log, there were a number of problems and difficulties encountered during the *Dynamite* deployment. These can be categorized as follows:

9.3.1 Buoyancy Engine

The buoyancy engine started to behave abnormally on 21st June, when the ‘neutral’ position of the oil seemed to shift by 15cc, making the glider more buoyant. This is when the out-of-deadband errors started to appear. See Chapter 10 for more details.

9.3.2 Altimeter

The altimeter appeared to sense a false bottom due to possible layers of zoo-plankton. As with the *Bellamite* mission this was solved by changing a parameter in the mission file so that any echoes indicating a distance less than 8m was ignored. Due to the bathymetry and the potential for the glider to wander off course it was decided not to turn off the altimeter.

9.3.3 Battery Life

As shown in Figure 9.4, *Dynamite*’s battery appeared to run out of energy at a faster rate than *Bellamite*’s. Assuming that the batteries were identical it seems that either two gliders either have different energy consumptions or there was an underlying fault in *Dynamite*. Following investigations into the buoyancy engine problems it now seems very likely that the latter was the cause of the higher energy consumption.

The rate of energy consumption has major implications for the mission endurance and meant that *Dynamite* left her station at EBH4 earlier than planned. By day 40 it was clear that the rate of decrease of the load voltage was faster than that of the previous deployment. A number of energy saving measures were tested but it is unclear at the moment what effect these had on the rate of energy consumption given the other problems with the Iridium and buoyancy engine. They were a) reducing the amount of oil transferred in the yos, in effect reducing the speed of the glider. b) fixing the battery pitch position rather than commanding a fixed pitch, and c) decreasing the sampling rate of the CTD. It should be noted that the fixed battery position worked very well until the final day of the deployment. The changes in pitch observed due to the increasing density of the ocean with depth were actually smoother and steadier than that of the ‘fixed’ pitch (Fig 9.8). For more discussion on the causes of the increased energy consumption see Chapter 10)

Footnote: Webb Research has developed a Coulomb counter circuit to measure energy use. *Dynamite* is to be retrofitted with this to aid future missions.

9.3.4 Software

There was a software bug that miscounted the number of yos to perform after a timeout leading to one or three yos performed. This affected the predictability of the surfacings and made it more likely for the glider to spend longer times on the surface.

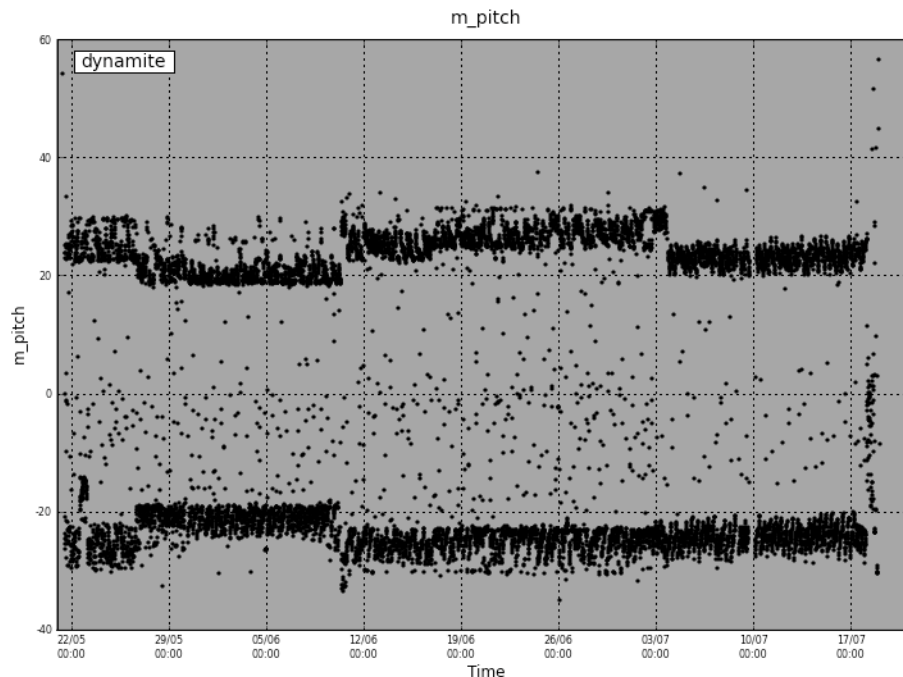


Figure 9.8 *Pitch angles of the Dynamite deployment.*

9.3.5 Iridium Communications

The Iridium communication was better than previous deployments. However, there were still some occasions there was no connection with the glider for well over 24 hours. It is suspected that two of the previous comments from Chapter 6 are still valid: location of the glider and possibly volume of traffic. It was noted that the glider did not always make contact with the dockserver during office hours. Wireless internet connections were often found to be too unstable to maintain the continuous SSH connection from a laptop to the dockserver. There were some errors associated with the Iridium system aboard the glider herself, which have not been investigated further yet.

Dynamite was configured to use the RUDICS system rather than the traditional voice Public Switched Telephone Network (PSTN). Essentially this changes the method of transferring data between the dockserver and the Iridium gateway (Fig 9.9). The idea is that the connection over a modern internet line with T1 hubs should deliver data more reliably than the older telephone lines, with an added benefit of reducing the initial time required to establish a connection by up to 40 seconds as there is no modem to be trained. Therefore the call drop out rate should decrease. The set up costs are higher (~US\$2500) although the data cost is cheaper at approximately US\$0.65 rather than approximately US\$1.00 per minute. It seems likely that any lack of communication was due to the location of the glider and the satellite coverage or bandwidth rather than the terrestrial side of the system. The above costs are based on Griffiths and Smeed 2009.

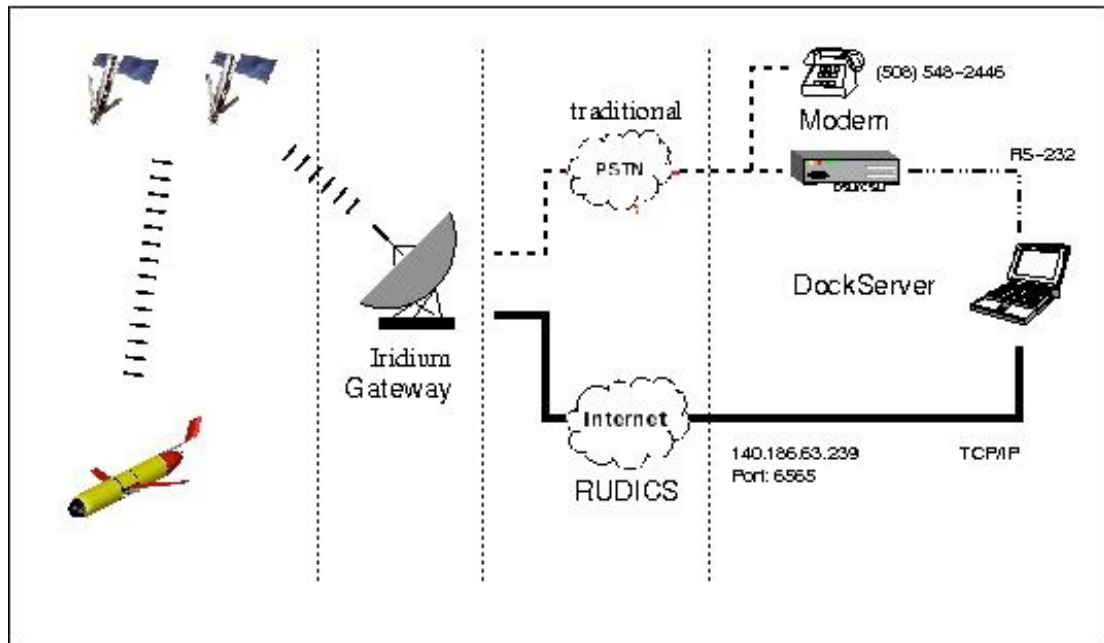


Figure 9.9 Glider Iridium connection paths (from Dock Server User Guide pg 135)

9.3.6 Navigation Error

On the 4th June the glider strayed off course by 4km to the east. Whilst it is not totally clear what caused this one off event it is suspected to be a tidal effect caused by the increased underwater time of 3 yrs after a timeout. After this the glider navigated as expected.

No.	Date	Time (GMT)	Filename (dynamite-2009*)	segment	reason
1	23 May	13:01:39	140-4-14	0040.0014	Device error
2	26 May	14:13:30	142-0-24	0041.0024	Device error
3	30 May	03:58:03	145-0-24	0042.0024	Behaviour error
4	30 May	04:18:10	149-0-0	0043.0000	Behaviour error
5	30 May	04:52:15	149-1-0	0044.0000	Behaviour error
6	30 May	05:24:57	149-2-0	0045.0000	Behaviour error
7	30 May	05:44:41	149-3-0	0046.0000	Behaviour error
8	30 May	06:04:22	149-4-0	0047.0000	Behaviour error
9	30 May	06:24:07	149-5-0	0048.0000	Behaviour error
10	30 May	06:56:43	149-6-0	0049.0000	Behaviour error
11	10 June	06:33:15	149-7-64	0050.0064	Device error
12	16 June	17:57:27	160-0-36	0051.0036	Device error
13	21 June	08:34:25	166-0-22	0052.0023	Device error
14	25 June	09:46:47	171-0-23	0053.0023	Device error
15	1 July	22:35:04	175-0-40	0054.0040	Device error
16	3 July	16:55:23	181-0-11	0055.0011	Device error
17	12 July	20:10:53	183-0-50	0056.0050	User interrupt
18	18 July	08:54:50	198-0-0	0058.0000	Same depth
19	18 July	10:18:46	198-1-0	0059.0000	Same depth
20	18 July	13:19:45	198-2-0	0060.0000	Same depth
21	18 July	16:20:47	198-3-2	0061.0002	Leak
22	18 July	17:26:56	198-4-0	0062.0000	Leak
23	18 July	18:20:51	198-5-0	0063.0000	Same depth
24	18 July	20:42:51	198-6-0	0064.0000	Leak
25	18 July	21:24:39	198-7-0	0065.0000	Leak
26	18 July	21:54:16	198-9-0	0066.0000	Leak
27	18 July	22:31:11	198-9-0	0067.0000	Leak
1	18 July	23:41:42	198-11-1	0069.0001	Leak
2	19 July	00:22:24	199-0-0	0070.0000	Leak

Table 9.1 *Abort History*

10 Examination of the Glider *Dynamite*

Paul Wright and David White

Following the recovery of *Dynamite* by the Gran Canaria SAR and ICCM, a post recovery examination was carried out by Paul Wright and David White on the 4th – 5th August 2009.

10.1 Outline

With the glider on the bench, the FreeWave was set up and the glider was powered up. After some basic checks a log file, 00750000.dbd, was opened and the oil volume changed from -300 cc to +300cc and back. This clearly demonstrated the basic problem with the buoyancy engine discovered during the night of the 18th July. When the oil is in the forward bladder it cannot maintain its volume against the pressure gradient of the water (or this case, atmospheric) pressure and the partial vacuum inside the glider. The possibilities are i) the check valves in the pump are leaking, allowing the high pressure oil to flow back through, ii) the thermal valve is leaking and iii) the thermal valve is in the open position. It was established and confirmed by Webb, that the valve and pump are arranged in parallel (Fig 10.1).

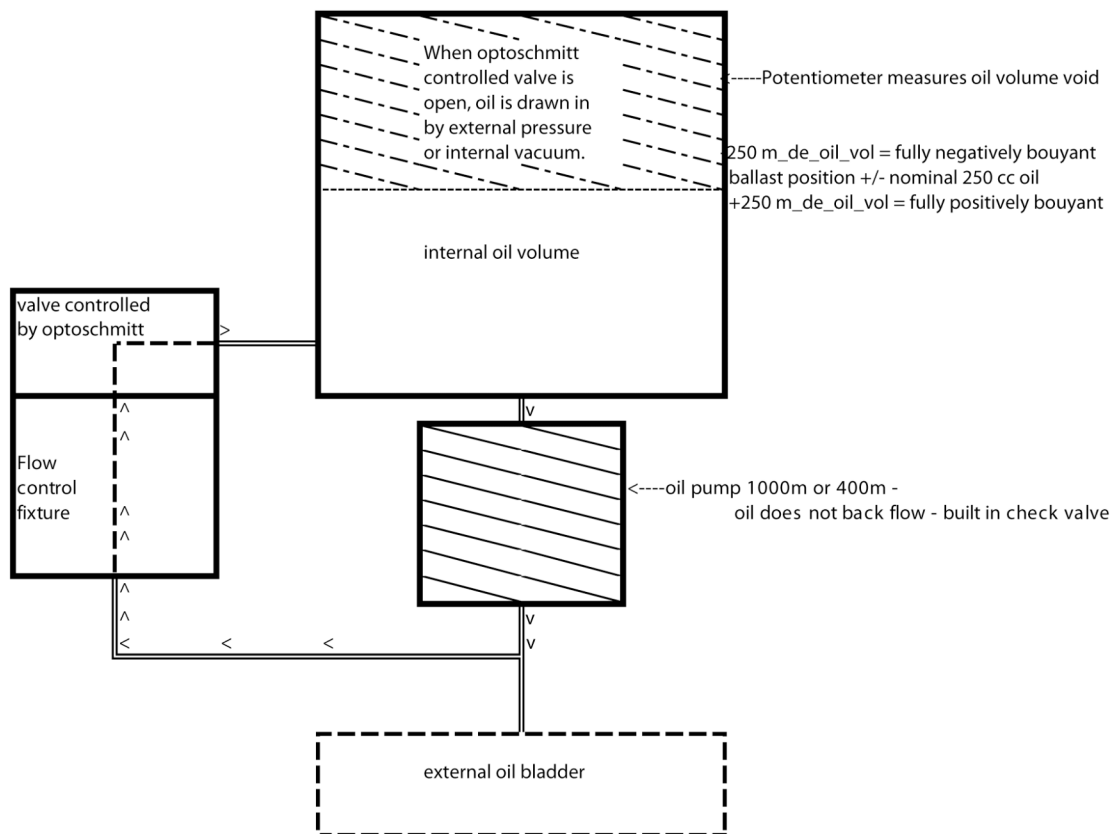


Figure 10.1 Schematic diagram of the buoyancy engine (courtesy of Webb Research). The so-called thermal valve is located on the left of the diagram.

Before work started on the buoyancy engine and dismantling the glider, a series of checks and measurements of the digifin was carried out as requested by Webb Research. (see Appendix D). The 15 minute digifin wiggle was recorded in the file 00760000.dbd.

The glider was subsequently dismantled and every accessible part of it was carefully inspected.

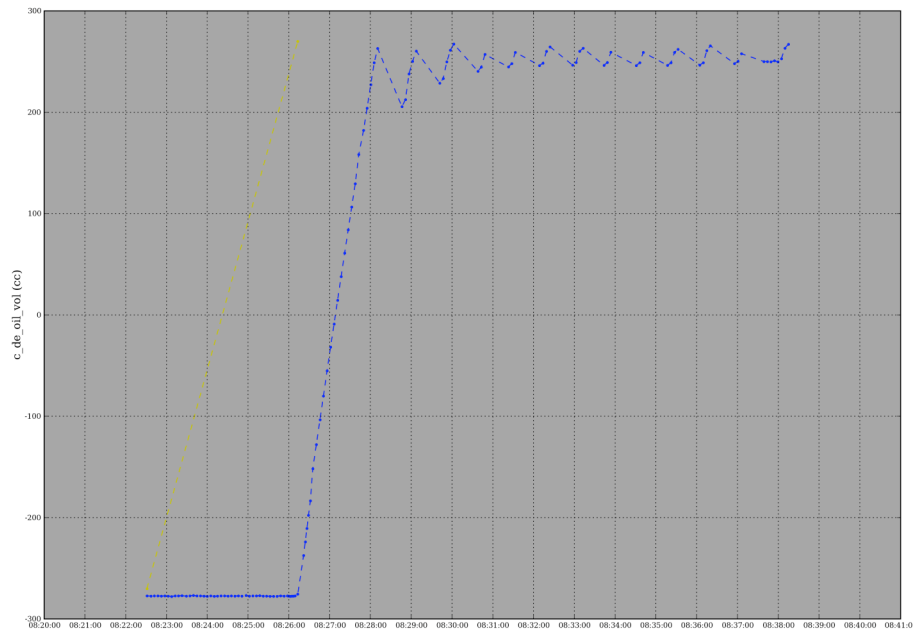


Figure 10.2 *The first test run of the glider after recovery. The inability of the buoyancy engine to maintain a stable oil volume when in ascent (buoyant) mode is clear to see. The yellow trace represents the commanded values.*

Aft section: small amounts of salt crystals were found on the underside of the aft battery array. When the aft (transom) plate was removed traces were found of a minor seepage through the tail boom joint. This was tightened up before deployment by Lucas and Paul when some play was discovered. A video of the movement was emailed to Webb by Lucas and a 32 mm spanner bought to tighten it up. Due to the limited access this was very tricky. At this point in time it is unsure if Webb had given Lucas a specific torque setting. To get a socket and a torque wrench on the nut would require the dismantling of all the cabling on the aft electronics tray.

To remove the transom plate required the use of small screwdrivers and several minor nicks were made in the non-sealing parts of the anodized aluminium. This will require smoothing off with emery paper and repainting before the next deployment. Other methods were used to try to remove the transom plate with no success. The aft anode was severely corroded. The memory card was removed and the data downloaded. The rudder (digifin) control board was inspected and the resistor that Webb asked us to look for was indeed missing. Therefore the board was of the dodgy batch identified by Webb.

Traces of salt water/crystals was found on the Teflon sheet beneath where the battery sits. No water or corrosion or salt was found on the leak detectors. The lower points of the leak detectors were coated with grease. It was concluded that some of the sealing grease had splurged out and waterproofed them for the lowest 1 mm during the final assembly process. The pitch battery was firmly attached (one of the suspicions of the change in angle/buoyancy during the mission). No evidence of water on the battery

although damp patches were found under the Teflon sheet. There were no obvious signs of damage or loose fixings on the buoyancy engine. All ballast was secure. There was, however, a large air bubble in the buoyancy engine low pressure pipe work, indicating that air is permeating into the system, which is likely to have had something to do with the sudden change in the neutral position that occurred on 22nd – 23rd June, Fig 10.4. On removal of the nose cone the forward anode was also found to be completely corroded. The aft anode was also completely corroded. This raises the possibility of an earth leak in the electrical system of the glider. There was no sign of corrosion on the altimeter connector or the membrane plate.

It was concluded after inspection of the log file 0075.0000.dbd that the excessive energy consumption was due to the buoyancy engine working more frequently to maintain oil volume in the external bladder (Fig 10.4). On further inspection (armed with this knowledge) of Fig 9.5 it seems that the valve problem started on the 21st June with the spreading of the oil volume measurements. Initially the stability of the oil volume on the ascent mode of the glider was somewhat puzzling and some time was spent trying to reason this out using basic physical principles.

The glider was reassembled and more tests were performed on the buoyancy engine to confirm our theory of the engine ‘hunting’ to find the correct value (Fig 10.4). The valve is closed after the oil has been moved to the internal reservoir by the pressure gradient – the pump is not used. It appears that the glider can maintain a steady oil volume at various volumes, within the deadband limit – at least against atmospheric pressure after a period of hunting. The ‘thermal valve’ commanded and measured positions were recorded as suggested by an email from Webb (see Chapter 9, 24th July 2009). Following a conversation with Webb, it was concluded that there exists a software problem. The drivers for the pump and the valve conflict at various times. This could be seen on the report ++ list when at times the valve was not commanded to close. No attempt was made to run the buoyancy engine without the pressure case closed and a vacuum applied. According to the manual this is possible for the deep engine, but it was not clear that there was any benefit to be had. There is a possibility that the sensor that measures the internal reservoir volume is loose/not functioning correctly, although the zero errors are more likely to have been caused by the air present in the reservoir. No attempt was made to disassemble the buoyancy engine as Webb agreed to repair the glider under warranty.

10.2 Possible Time Line

21st May - deployment

30th May - glider spent the night on the surface with no discernable consequences.

21st June - sudden change in the behaviour of the buoyancy engine – due to air bubble? Glider effectively lighter than expected. 0053.0001.dbd

23rd June - The glider performed a very shallow yo from 03:45 to 04:00 (possibly due to zoo-plankton) and the oil volume slowly decreases from the initial value of 270 cc. This is potentially the first sign of change of the buoyancy engine, ref: 0053.0012.dbd. Also during the early yos occasionally on the beginning of the dive and the oil is returning to the internal reservoir, the oil volume overshoots to the maximum value of -270cc. It is quickly corrected. This is likely to be due to the software problem identified by Webb

earlier. The valve does not close – likely to be because the oil volume measurements/valve commands/positions are not being received by the processor or the valve. From 23rd June onwards the air/valve problem is now obvious. With 10:00 → 11:30, on a time out rise the oil volume is requiring the pump in order to maintain volume, the most clear-cut example.

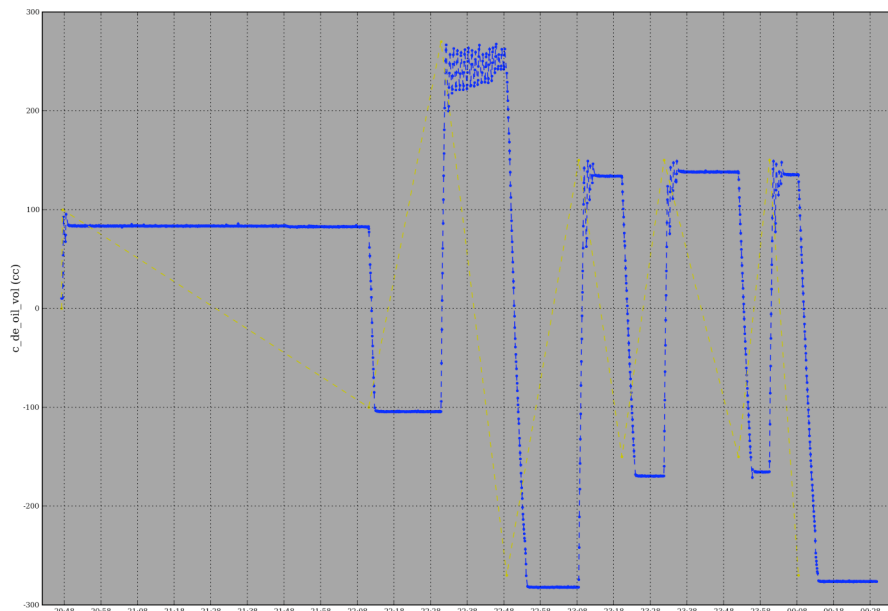


Figure 10.4 *Final run of the buoyancy engine at various commanded values to show the hunting.*

21st June – 18th July – increased drain on the batteries due to excessive use of the buoyancy engine pump.

17th July – glider out of Iridium contact for 24 hours. Reached waypoint, failed to upload the new goto file. Glider remained on the surface throughout the night. More air in the buoyancy engine. Possible intake of water through the tail boom fixing.

18th July – new goto file manually uploaded. Glider failed to perform dives as programmed. Aborts due to same depth due to a combination of deep wave motion underwater and excess buoyancy. On abort the increased buoyancy sharply increased the pitch. This sequence of events was repeated throughout the day 6 times. At some point the water that had entered the glider triggered a leak_detect abort. After that, operators found they were unable to control the glider as it was unsure what was happening. It appeared to be leaking and yet far too buoyant to dive. The oil volume was unstable and as the problem with the valve was now apparent the mission was terminated.

10.3 Discussion

Oil Volume Changes: when the oil is moved inside the internal reservoir by the pressure gradient the valve is closed – resulting a stable oil volume. However, when the oil is moved to the external bladder by the pump the valve was left open for a variable period, due to a conflict between the software drivers for the thermal valve and the oil pump.

The behaviour then varied depending on the rate of return flow of the oil. Given that the valve should remain in the closed position while the oil is being pumped forward into the external bladder, it is not immediately clear why the valve should be open at all.

Zero Error: This was probably caused by a combination of dissolved or gaseous air in the oil shifting from the external high pressure bladder to the internal low pressure reservoir and consequently expanding and air bubbles forming in the external bladder after a long period on the surface. As the oil volume is measured from the internal reservoir, air would lead to the oil volume in the external bladder being measured as less than reality. Under normal operations the oil in the internal reservoir has a chance to de-gas, thus creating a small error while the oil in the bladder is normally under a high pressure, with only short periods of low pressure at the surface, and thus a limited period for de-gassing. During operation there will be an exchange of the slightly de-gassed oil with the more de-gassed oil from the reservoir, leading to a gradual build up of air in the reservoir (see Fig 6.2). Any air in the bladder will quickly dissolve into the oil as the pressure increases during the dive. As the glider spent some long periods on the surface more bubbles than usual may have formed in the bladder, which would increase the overall buoyancy. So, the zero error at the first stage of the problem is likely to have been caused by the rapid increase air in the internal reservoir and the major problems on the final days of the mission by a combination of the two.

Same depth aborts: as the glider spent the night on the surface nose down in rough seas with the oil in the external bladder with the pump running frequently, it is very likely that some air in the external bladder migrated into the internal reservoir and other air bubbles caused an increase in buoyancy. The rate of diving was very slow. Additionally, due to the shallow depth achieved (approx 55m) and the deep wave action that extends to approx 5 times the height of surface wave/swell, the glider was frequently going up as well as down. As the dz/dt was often positive the same_depth abort was triggered. The glider needed very little change in oil volume to rise to the surface. The dive profile pitch was low and on the ascent the pitch shot up to roughly 58° as the nose was now far too buoyant.

Leak aborts: The traces of sea water in the glider are likely to have been far too small to trigger the leak detector, especially as the traces of O-ring grease on the contacts would have waterproofed them. As the glider spent the night on the surface in rough conditions it may also have been that the wave action on the digifin/tail boom worked on the joint with the transom, restarting the leak fixed by Lucas and Paul prior to deployment. The sudden large changes in pitch after the same_depth abort (Figure 10.3c) could well have caused the water to touch the contacts, thus triggering the leak_abort and then as the water i) moved away from the sensors or ii) evaporated due to the heat of the over worked batteries the leak detect voltage returned to normal and absorbed by the dessicant bag. There was no trace of salt, stains or corrosion on the contacts.

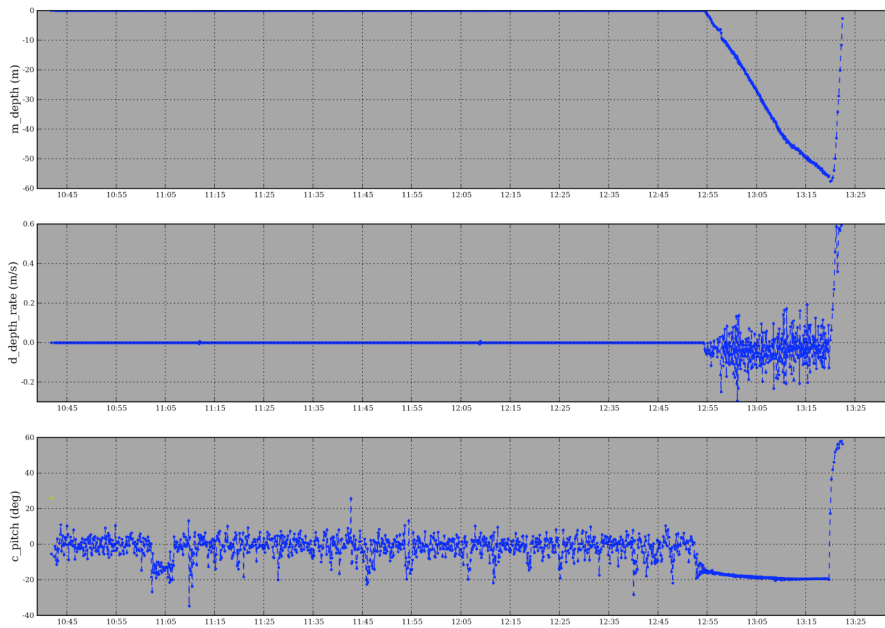


Figure 10.3 Plot to show the depth rate and pitch during the final stages of the deployment. It is clear from this why the glider aborted due to same_depth. It is suspected that the erratic rate of change of depth was due to a combination of wave motion and the inability of the glider to dive.

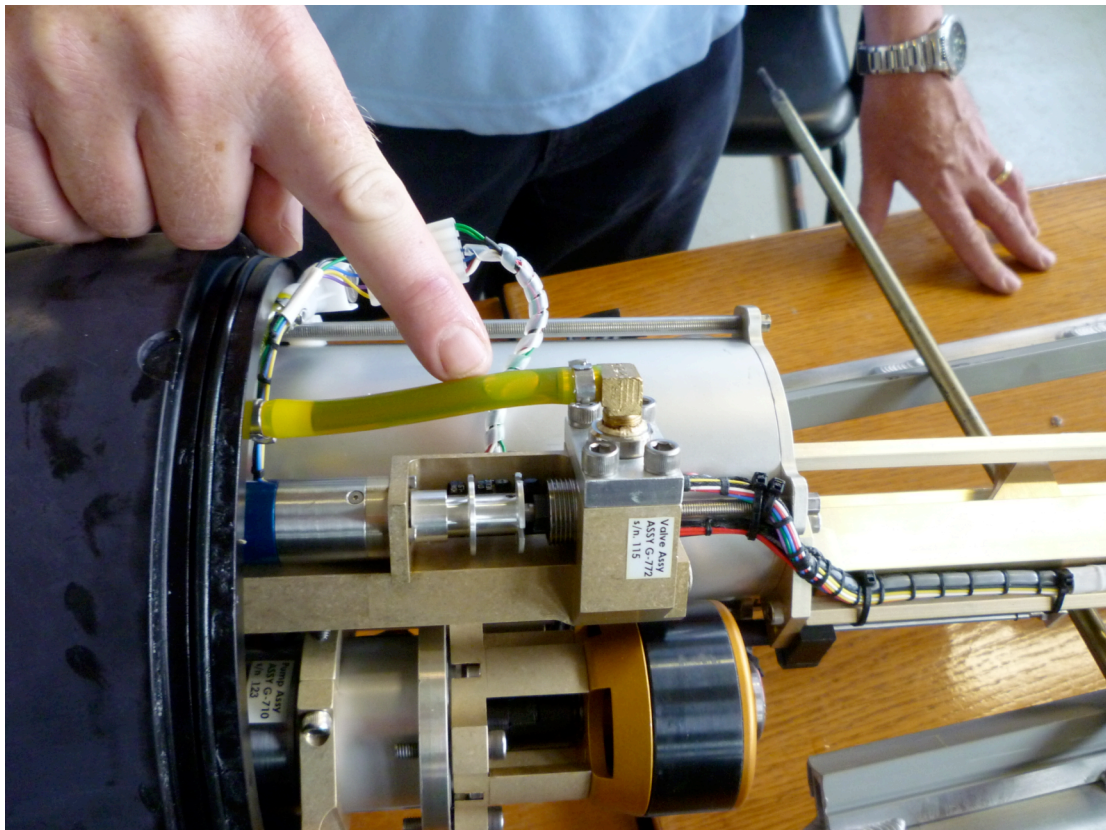


Figure 10.4 Photo to show air bubble in buoyancy engine pipework. The thermal valve motor is directly below the bubble. The main pump motor is below that.

10.4 Summary

The primary causes of the failure of the glider *Dynamite* were a combination of a software problem with the ‘thermal’ valve control in the buoyancy engine, air migrating into the buoyancy engine oil and a tiny leak through the tailboom nut. Individually, each of these problems could have been overcome and would not have caused the failure of the vehicle.

The nights spent on the surface, particularly the final night, due to the failure to upload a new goto file, exacerbated the problem. The pump had to run often to maintain the oil volume with the nose down, and the failure of the valve to close allowed much more of the air (bubbles) or partially degassed oil in the external bladder to move to the low pressure internal reservoir, disrupting the volume sensor to a greater degree than before. Additionally, the low environmental pressure on the external bladder would have allowed dissolved air to form bubbles, increasing the buoyancy further. Thus, the commanded and measured values of the oil volume required for correct functioning of the glider, were not enough to facilitate diving at a fast enough rate to overcome the deep wave/swell motion present at the time. The software controlling the leak and same_depth aborts was functioning as designed. The faulty thermal valve driver that stopped closing the valve when the oil was pushed forward caused the pump to run for much longer than designed and led to the faster than expected drain on the batteries. The tiny amount of water present should not have caused the mission to abort, but due to the large pitch changes and wave motion, the leak detectors were occasionally triggered, leading the pilots to believe that the glider was in more trouble than it actually was. It is possible that there may be another fault inside the buoyancy engine that we have not considered, such as a leak in the internal reservoir, but as the glider is to be repaired under warranty, no attempt was made to disassemble the engine.

With hindsight, *Dynamite* could have been commanded to overcome these problems and brought safely back to Gran Canaria, but as the information was limited and time was of the essence, it was very difficult to ascertain what was happening aboard. As with many such incidents, there was more than one failure mode and these led to a series of other symptoms/problems that confused and exacerbated the situation.

10.5 Recommendations

The following recommendations are suggested prior to another deployment:

- The older gliders should be checked for the newer software and checked to see if they have the same valve problem that *Dynamite* has. When Webb have issued an update for this it should be uploaded onto the fleet.
- The glider has been sent back to Webb for warranty work.
- Webb to be pressed for why air got into the oil – either their fix did not work or there was an air leak somewhere.
- The de-gassing techniques used prior to deployment may need more careful assessment to be sure that no dissolved gas is present in the oil prior to deployment.
- A detailed proforma check sheet to be used by the pilot(s) to check for subtle changes in the behaviour of the buoyancy engine and other engineering parameters, based on the experience gained during these deployments (and others). A draft is included in Appendix E.

- Piloting computers should ideally be set up with ethernet net connections and not be solely reliant on wireless, which can be unstable and disconnect without audible warning.
- Greater priority should be given to having a pilot ‘on watch’ to prevent long periods on the surface, especially during the night.
- A formal logbook of changes, events and the day-to-day management of the glider to be introduced.
- The goto_150.ma and yo_50.ma files should be set up earlier than required and be of such a format to avoid having the glider spend excessive amounts of time on the surface. i.e. to avoid surface time due to no waypoints, or conflicts within the ma files. It would appear that it is better to try to manually upload the .ma files rather than rely on the XML scripts.

10.6 Feedback from Webb

On the 20th August 2009 we received an email from Webb regarding the latest software upgrades and bug fixes for the gliders. Among the issues addressed is the buoyancy engine thermal valve.

11 Correcting Data and Calculating the MOC Anomaly – *Dynamite*

Paul Wright

11.1 Introduction

The data was first downloaded from the glider and converted into the more usable .mat format. A correction was applied in a similar manner to the *Bellamite* data (see Chapter 7) and the data post-processed to produce a MOC transport anomaly. At the time of writing the eastern boundary mooring array had not yet been recovered and therefore the data and results cannot be directly compared to the mooring data.

11.2 Data Processing and Formats

The real-time data is downloaded in the .sbd format to save costs. The more detailed .mbd and .dbd files are stored on the memory card aboard the glider. They are converted into ASCII and .mat files using the command line below entered into the relevant directory. For convenience, it is best if the programs dbd2asc.exe and dba2_glider_data.exe are located in the same directory as the data.

```
ls *.mbd | dbd2asc -s | dba2_glider_data
```

This produces two files;

```
dynamite_2009_XX_X_XX_mbd_gld.m  
dynamite_2009_XX_X_XX_mbd_gld.dat
```

or similar depending on the type of file converted. Once the MATLAB script has been run and the data loaded into MATLAB, another code, named dynamite_variables.m, will produce a .mat file with the principal variable names and changes the time variable to *jd_time*, which matches the RAPID standard.

There have been three raw data files produced:

```
dynamite_raw_sbd_data.mat  jd_time, elapsed_time, depth, pressure, temp, cond, pitch,  
                           oil_vol, lat, lon, gps_lat, gps_lon, lat_deg, lon_deg  
                           229353 lines – mean sample interval 22.12 s
```

```
dynamite_raw_mbd_data.mat  jd_time, elapsed_time, pressure, temp, cond, depth,  
                           depth_rate, avg_speed, gps_lat, gps_lon, lat, lon, oil_vol,  
                           pitch  
                           1083851 lines – mean sample interval 5.99 s
```

```
dynamite_raw_dbd_data.mat  jd_time, elapsed_time, pressure, temp, cond, depth,  
                           avg_speed, gps_lat, gps_lon, lat, lon, oil_vol, pitch,  
                           batt_pos, cycle_number, depth_rate, iridium_call_num,  
                           iridium_dialed_num, mission_avg_speed_climbing,  
                           mission_avg_speed_diving, speed, thermal_valve  
                           1092472 lines – mean sample interval 5.94 s
```

The files are found in the directory:

rapid/data/glider/dynamite/data_files/RAW_DATA_MAT_FILES/

11.3 Correcting the CTD Data

Pressure, temperature and conductivity are all required to calculate potential temperature and salinity. The temperature and conductivity have a number of sources of errors due to: the 10 cm difference in physical location, the thermal inertia of the glider and the different response times of the instruments (see Chapter 7). Due to the large thermal gradient found in tropical waters the thermal inertia is likely to be a noticeable effect.

These errors result in a separation between the upcasts and downcasts on the $S - \theta$ profile. The basis of the correction is to bring the two profiles together to form a unique profile for the water column (Figs 7.4 and 11.1). As the temperature is needed to calculate the salinity from the conductivity measurements either the temperature or the conductivity need to be time corrected. Merckelbach demonstrated in Chapter 7 that the two methods were equivalent. It is easier to correct the temperature from T to T_C .

$$T_C = \int_{-w}^t H(t-t')T(t')dt' \quad (11.1)$$

where w is some time in the past, H the weighted transfer function and t' the previous time step of the data.

As we are using discrete data rather than continuous data, the above equation becomes:

$$T_C(t_i) = \sum_{j=i-N}^i H(t_i - t_j)T(t_j) \quad (11.2)$$

where N is the number of steps to include in the averaging behind i . This can be expressed in terms of a series

$$T_{C,i} = T_i b_1 + T_{i-1} b_2 + T_{i-2} b_3 + \dots + T_{i-N} b_{N+1} \quad (11.3)$$

where, b represents the discrete components that constitute the continuous transfer function H . In MATLAB there is a function that can do this, $T_c = \text{filter}(b, a, T)$. Normally $a = 1$. For a better correction b can be chosen such that an exponential decay is used, with the denominator ensuring that $\sum(b) = 1$. The variable, b would now be better described as a weighting function with a length N that is the filter window.

$$b_j = \frac{e^{-j\Delta t/\tau}}{\sum_{j=1}^N e^{-j\Delta t/\tau}} \quad (11.4)$$

where, Δt is the time step interval, τ the relaxation time. The filter window, N , was set to be 20, which corresponds to approximately 90 seconds. *Dynamite* had a faster sampling rate than *Bellamite*. The task was to find τ , which for *Bellamite* was approximately 4 seconds (see Section 7.2.2). However, this is not a constant and was expected to be a function of the velocity of the water through the CTD cell.

The first step was to determine the speed dependence. An optimization routine was created to find the value of τ that brought the up and down casts closest together, based

on 12-hourly binned data. The correction was quantified by sampling the temperatures at regular intervals, taking care to avoid the mixed layer, and comparing the standard deviation of the salinity before and after correction. From this code, `dynamite_optimal_tau.m`, the following empirical relationship was found between τ and the water velocity, v , (Fig 11.3),

$$\tau = \frac{2.305}{v} - 0.483 \quad (11.5)$$

The MATLAB code was then edited to base the relaxation time, τ , on the empirical dependence on the velocity of the water through the cell. A close correlation was found between the ratio of salinity standard deviation values from the optimization routine and that found from using τ based on the water velocity (Fig 11.4). Once the concept was determined to work, the routine was further modified to correct the data at every time step, based on the smoothed water velocity. The code used was:

```
rapid/data/glider/dynamite/m_files/  
dynamite_CTD_correction.m
```

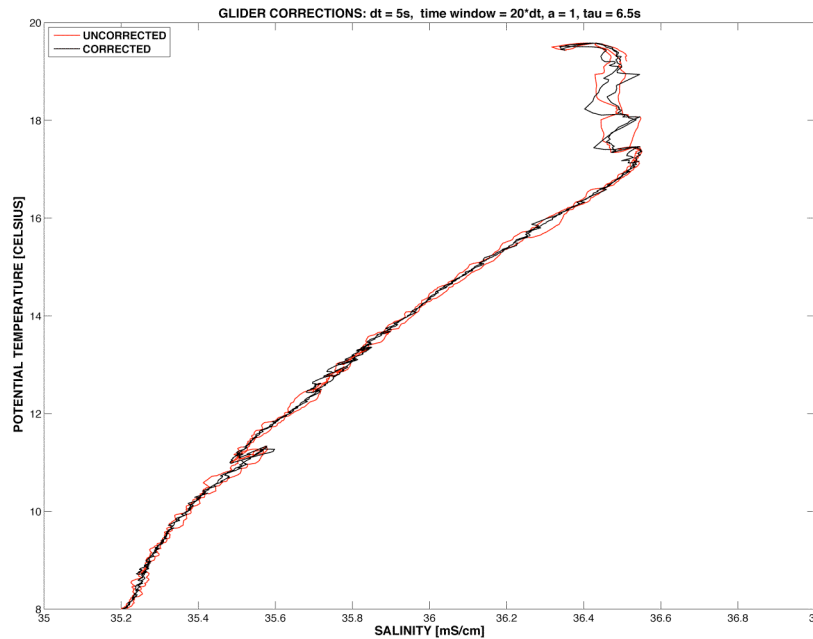


Figure 11.1 A $S - \theta$ profile after the temperature correction. Note how the corrected up and down casts are closer and more like a single profile.

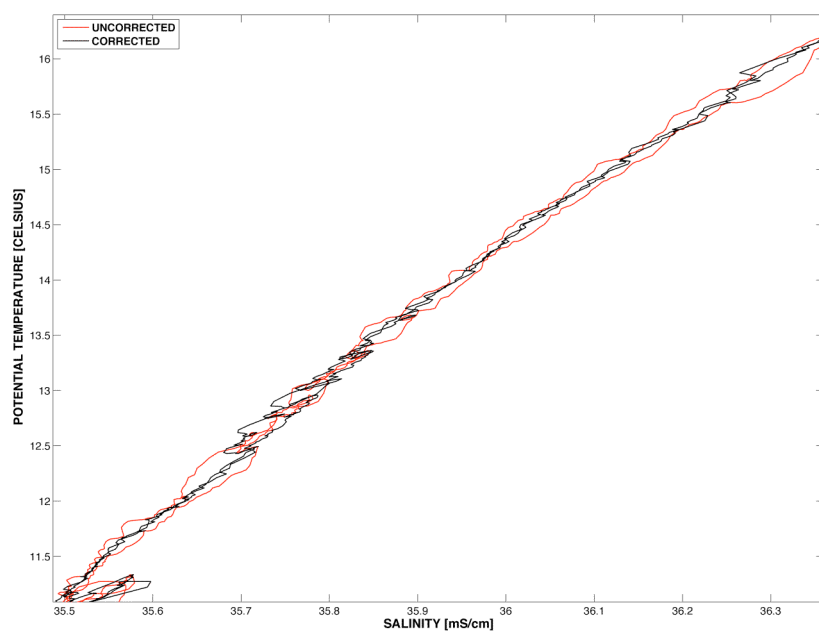


Figure 11.2 *A close up of the centre section of Figure 11.1*

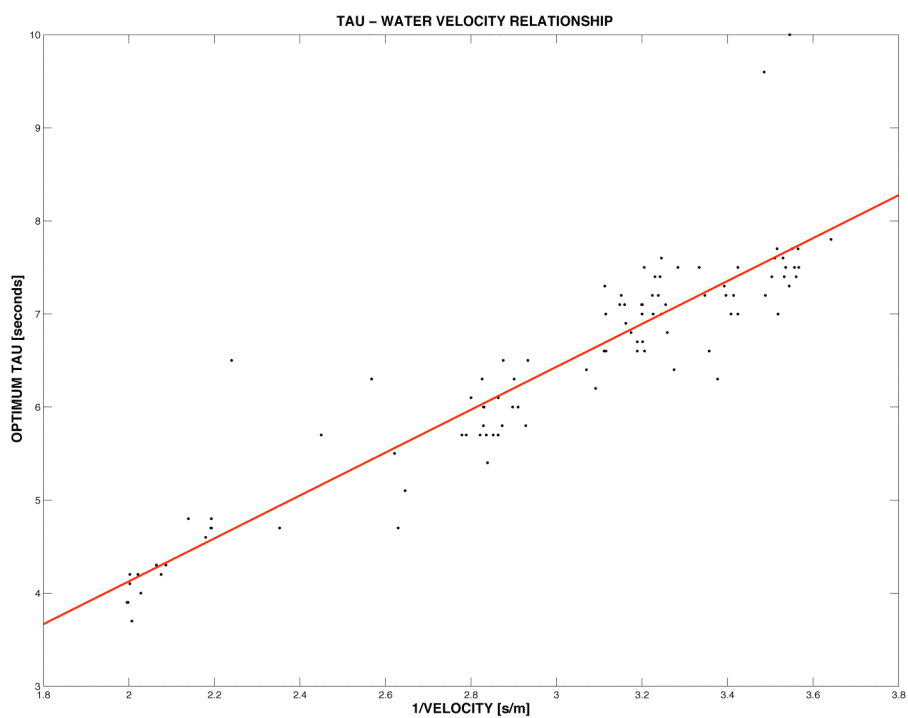


Figure 11.3 *Relationship between τ and the velocity of the water through the CTD cell for Dynamite.*

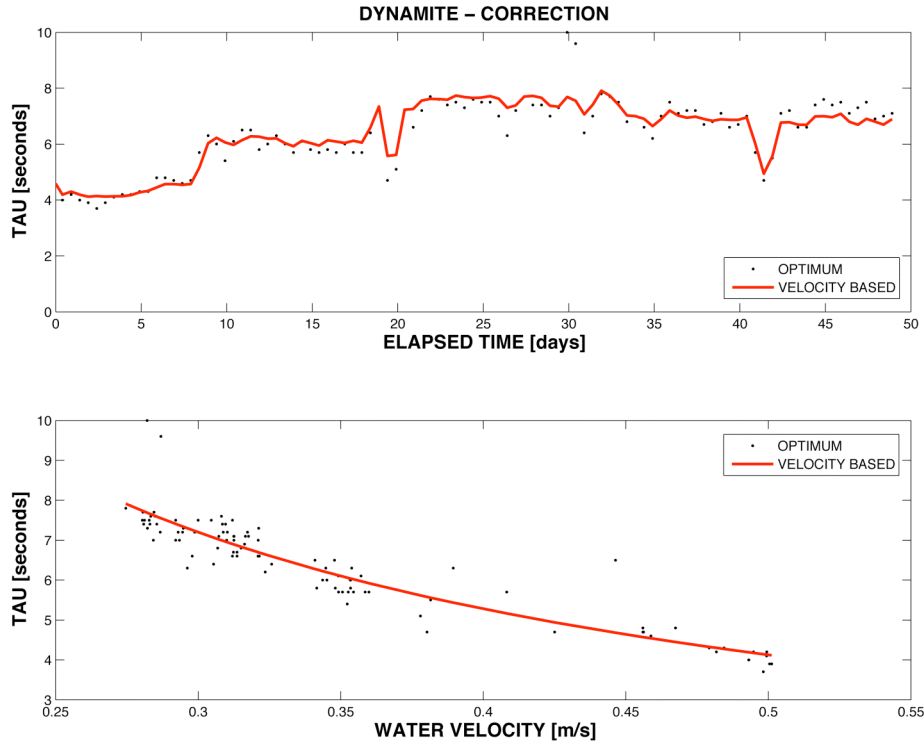


Figure 11.4 The relaxation time, τ , for the Dynamite data based on the optimum needed to converge the up and down casts and the velocity of the water through the CTD cell. The velocity based result is presented as a continuous curve for clarity.

The corrected data has been saved as:

```
rapid/data/glider/dynamite/data_files/corrected_data.mat
```

It is important to note that while the data has been corrected it has not been calibrated. For that we need to wait until the mooring data has been recovered and post-processed.

11.4 The MOC Anomaly

The corrected data was restricted to a region 20 km radius from EBH4 and gridded onto the RAPID standard 20-dbar 12-hourly grid to produce the MOC anomaly time series due to the shallow eastern boundary in the same manner as the *Bellamite* data (see Chapter 8). While 20 km is a rather large radius, the glider generally stayed less than 4 km from the mooring for all but two occasions. By choosing a 20 km cut-off, large data gaps that would require interpolation are avoided. The codes used were: `dynamite_glider_data_gridding.m` and `glider_MOC_anomaly.m`.

The eastern boundary merged data from EBH4 and the inshore moorings are based on the pressure range 120 \rightarrow 860 dbar, while the glider measures from the surface to 980 dbar. As the thermal gradient is steep near the surface and therefore not captured by the moorings, the MOC anomaly has been calculated for both pressure ranges for completeness.

The mooring EBH4 is scheduled to be recovered during the RRS *Discovery* cruise in October – November 2009 and a more detailed comparison can be carried out with the *Dynamite* data once the mooring data has been recovered and post-processed.

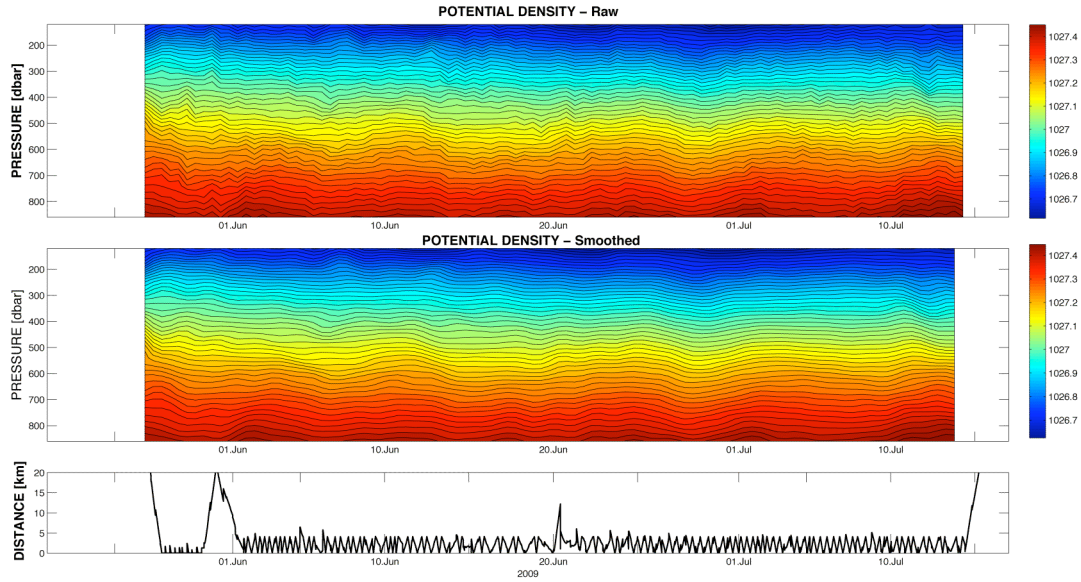


Figure 11.5 The gridded and smoothed *Dynamite* data for the RAPID 2009 deployment.

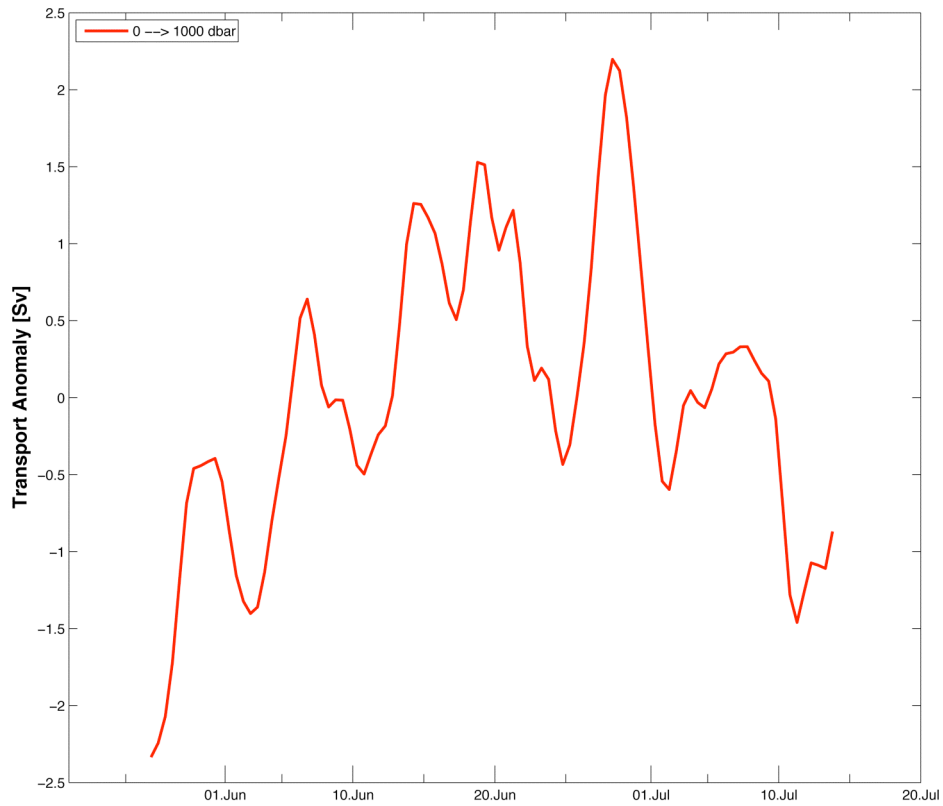


Figure 11.6 The MOC anomaly due to the eastern boundary variability as calculated from the glider *Dynamite*.

11.5 Summary

An analysis of the CTD data from the gliders *Bellamite* and *Dynamite* used in the RAPID deployments show that the temperature data is slightly out of phase with the conductivity data. A large part of the effect can be attributed to the speed of the water through the CTD cell. A simple filter, used to adjust the temperature, was applied prior to calculating the salinity and potential temperature of the water column was used to correct for this. An optimization routine was used to find the value of the relaxation time, τ , that allowed the best correction over the duration of the deployment. From these time-dependant results it was determined that the relaxation time scale for this effect was dependent on the speed of the glider through the water, varying from 4 to 8 seconds, according to the empirically derived relationship (11.5).

This empirical relationship for the relaxation time of the filter was then applied in a routine to correct the temperature and calculate the resulting salinity and potential temperature. These were then gridded onto the RAPID standard pressure – time grid and used to calculate the MOC anomaly due to the eastern boundary variability. At the present time this cannot be directly compared to the mooring data.

Possible further work on this could be to further refine the procedure to investigate and include the effect of the thermal gradient.

A clear benefit of the glider over the moorings is that, with these routines in place and assuming a speed correction factor, it will be possible to automate the correction of the data downloaded from the glider via Iridium on a twice-daily basis and include them directly into forecast models.

12 Requirements for Continuous Monitoring at EBH4/5

David Smeed

From our experience so far we are able to estimate the cost of continuous monitoring using gliders. Assuming an endurance of 72 days and allowing 6 days for transit each way to and from the monitoring site each glider deployment would be able to complete 60 days of monitoring. This would require 6 deployments per year. Excluding capital and staff costs the main costs are:

- Batteries c. £3,800 per deployment.
- Iridium charges c. £7,500 per year.
- Travel and subsistence for staff to assist deployments and recovery c. £1,200 for each trip.
- Freight of glider to Gran Canaria c. £1,250 each way.

Currently ICCM do not charge us for the use of their facilities.

A minimum of two gliders would be required for continuous monitoring, however, it would be advisable to have a third available as a backup. This would also reduce the time that staff would need to spend on Gran Canaria. On each one-week trip they would be able to deploy one glider and service (change batteries etc) the standby glider. ICCM staff would recover the third glider the following week (we do not think it is necessary for NOCS staff to wait an additional week in Gran Canaria for the recovery). The annual cost of batteries, Iridium charges and travel would be about £44,000.

The assumed endurance of 72 days is what we have achieved for the two completed missions. However, we are hopeful that this could be increased to 100 days so that only 4 deployments would be needed each year. This would reduce the costs to £32,000.

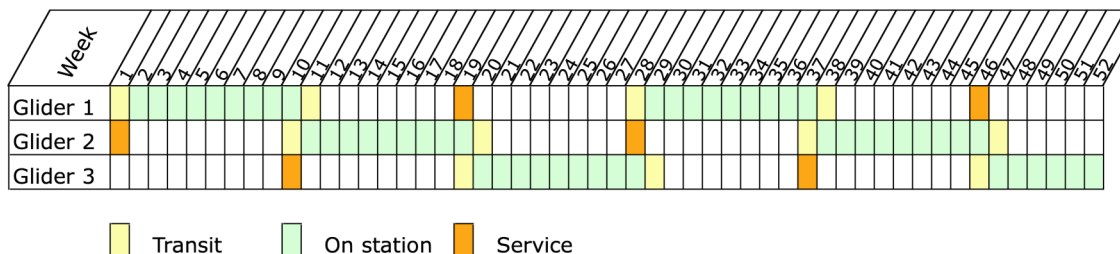


Figure 12.1 *Proposed schedule for continuous monitoring with 3 gliders.*

13 Conclusions

The recommendation is to continue with the trial glider deployments for the near future. The capital outlay has already been made, the potential benefit to the RAPID–MOC programme has been established from the data analysis and the operating cost per deployment is relatively low, certainly significantly less than that of ship time. With every deployment the technical experience of the operating team improves and the overall reliability of the gliders is expected to improve rapidly. (Euridge 2008) It is expected that the post-processing of the data will become standardized and able to be produced much more quickly than at present.

As the shallow eastern boundary plays a key role in the overall MOC variability gliders have the potential to capture this in more detail and more reliably than the existing moorings. Additionally as the data is received in near-real time it has the potential – once calibration and correction routines are formalized – to aid with the forecasting models. It should be noted that telemetry with the moorings has so far not been successful due to the practical difficulties of maintaining a surface buoy on the moorings. In order to make continuous profiles it is anticipated that at least two gliders are deployed with an overlapping period. i.e. one replacing the other on site.

There has been a great deal of discussion of the best flight path of the gliders. *Bellamite* originally was to follow the bathymetry from EBH3 to EBM1, but that was abandoned due to technical problems with the altimeter. *Dynamite* solely acted as a full depth virtual mooring at the EBH4 site. The difference between the *Bellamite* data and the merged mooring data is likely to be due to the spatial distance between them.

It is likely that we would need two or more gliders on deployment simultaneously to capture the full profile required, one inshore on the shelf and another one working the 1000m profile and merge the data in a similar manner to the current mooring scheme. The ability of the glider to change location means that we have the potential to be imaginative in our approach to measuring the MOC on the eastern boundary.

The long endurance thermal gliders may also be considered, as they have much longer mission duration as their buoyancy engines are ‘powered’ by the temperature gradient at the top and bottom of the yos. As the RAPID program is based in the tropics with a strong thermal gradient these gliders may be an ideal solution to the observational problems with monitoring the eastern boundary on a continuous basis.

References

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Appendix A - Program Files

rapid.mi

```
# For flying a section near the canary islands
# Retrieves waypoints from mfiles/goto_150.ma
# Retrieves envelope from mfiles/yo50.ma
# Retrieves climb to surface controls from mfiles/surfac50.ma
# Retrieves sample from mfiles/sample50.ma
# 10-Sept-00 lmm@noc.soton.ac.uk Initial, cloned from gol.mi as of the
# end of the GOL 08 experiments.
# 20 May 09 Prepared for rapid 09 mission. copy from bellamite
# removed hacks for altimeter, and changed c_profile_on 0 to
# c_science_all_on 0 to be used with science persitor#
# 21 May 09 changed c_science_all to 4 as irregular on the 0 setting

behavior: abend

# MS_ABORT_OVERTIME

    b_arg: overtime(s)                                -1 # < 0 disables
#    b_arg: samedepth_for(s)                            1200 # <0 disables
    b_arg: samedepth_for(s)                            600 # set back to 1200 when
confident
    b_arg: samedepth_for_sample_time(s)                30 # how often to check
    b_arg: max_wpt_distance(m)                        300000 # MS_ABORT_WPT_TOOFAR
    b_arg: stalled_for(sec)                            -1 # <0 disables

#Come up if haven't had comms for a while, xx hours, defined in surfac51.ma

behavior: surface

    b_arg: args_from_file(enum)                        51 # read from mfiles/surfac51.ma
    b_arg: start_when(enum)                            12 # BAW_NOCOMM_SECS 12, when have
not
# had comms for WHEN_SECS secs
    b_arg: end_action(enum)                            1 # 0-quit, 1 wait for ^C
quit/resume, 2 resume, 3
# drift til

"end_wpt_dist"
    b_arg: keystroke_wait_time(sec) 300 # How long to wait for control-C

# Come up every X half cycles as determined by yo
# This is determined the completion of yo leaving the stack idle

behavior: surface

    b_arg: args_from_file(enum)                        50 # read from mfiles/surfac50.ma
    b_arg: start_when(enum)                            1 # 0-immediately, 1-stack idle
2-pitch idle 3-
# heading idle 6-when_secs, 7-when_wpt_dist
    b_arg: end_action(enum)                            1 # 0-quit, 1 wait for ^C
quit/resume, 2 resume
    b_arg: gps_wait_time(s)                            300 # how long to wait for gps
    b_arg: keystroke_wait_time(s)                      300 # how long to wait for
control-C

behavior: goto_list

    b_arg: args_from_file(enum)                        50 # read from mfiles/goto_150.ma
    b_arg: start_when(enum)                            0 # 0-immediately, 1-stack idle 2-
heading idle

behavior: yo

    b_arg: args_from_file(enum)                        50 # read from mfiles/yo50.ma
```

behavior: prepare_to_dive

b_arg: start_when(enum)	0	# 0-immediately, 1-stack idle 2-
depth idle		
b_arg: wait_time(s)	300	# 12 minutes, how long to wait
for gps		

behavior: sample

b_arg: args_from_file(enum)	50	# >= 0 enables reading from
mafiles/sample<N>.ma		

behavior: sensors_in

# b_arg: c_profile_on(sec)	5	# measures every 5 seconds
b_arg: c_science_all_on(sec)	4	# as fast as possible
b_arg: c_att_time(sec)	0	# as fast as possible
b_arg: c_alt_time(sec)	8	# as fast as possible
b_arg: c_pressure_time(sec)	0	# as fast as possible
b_arg: u_battery_time(sec)	10	
b_arg: u_vacuum_time(sec)	10	
b_arg: c_gps_on(bool)	0	# Special, 1 is on, 0 is off

goto_150.ma

behavior_name=goto_list

```
# 20 May 2009 added 2 waypoints in 400 m of water off Gran Canaria for
# deployment
# 22 May 2009 changed waypoint to take glider from Fuerteventura to EBH4
# 23 May 2009 removed Waypoint near Fuerte, as device error caused to go
# back to this one
# 26 May 2009 added waypoints N and S of EBH4
# 30 May 09 lmm@ changed initial waypoint -2 -> -1, preventing it to return
# to same waypoint all the time a ma file gets updated.
# 01 June 2009 PGW changed waypoints to keep glider closer to EBH4
# 14 July 2009 PGW changed waypoints to send glider back towards Fuerteventura
# 16 July 2009 PGW added waypoint off Gran Canaria
```

```
<start:b_arg>
b_arg: start_when(enum) 0 # BAW_IMMEDIATELY
b_arg: list_stop_when(enum) 7 # BAW_WHEN_WPT_DIST
b_arg: list_when_wpt_dist(m) 50 # used if list_stop_when == 7
b_arg: initial_wpt(enum) -2 #
# >=0: start with this waypoint,
# -1 the after the last achieved
# -2 closest

b_arg: num_waypoints(nodim) 2
b_arg: num_legs_to_run(nodim) -2 # Number of waypoints to sequence
# 1-N exactly this many
# waypoints
# 0 illegal
# -1 loop forever
# -2 traverse list once (stop
# at last in list)
# <-2 illegal
```

```
<end:b_arg>
<start:waypoints>
-1448.00 2750.00 # South of Fuerteventura
-1506.80 2754.2 # east of Gran Canaria
<end:waypoints>
```

yo50.ma

behavior_name=yo

```
# yo50.ma

# 20 May 2009 prepared single 300 m yo mission for deployment
# 21 May 2009 changed target depth from 300m --> 600 m to test altimeter
#           as water depth is approximately 700 m
# 21 May 2009 changed target depth to 980 m and from single yo to double yo
# 22 May 2009 changed downcast pitch to 15 degrees to maximise distance
# 22 May 2009 lmm@ changed down cast pitch back to 26 degr.
# 23 May 2009 PGW changed profile to 4 yos
# 23 May 2009 lmm@ changed profile to 2 yos because of yet unknown device error.
# 26 May 2009 PGW changed pitch to 22 degrees up and down
# 28 May 2009 PGW changed oil volume to +/- 150 to slow glider down
# 09 June 2009 PGW changed the oil volume to +/- 300 and the pitch to 30 degrees
# 10 June 2009 PGW changed the oil volume to +/- 100 and the pitch to 26 degrees
# 16 June 2009 PGW/DH/JC changed the climb pitch to 28 degrees
# 25 June 2009 PGW increased oil on descent by 50 cc due to unknown problems....*****
# 26 June 2009 PGW ascent = +75 descent -100
# 26 June 2009 DAS ascent +75 descent -150
# 1 July 2009 PGW ascent +225 descent -300
# 2 July 2009 PGW ascent +75 descent -150, battery position descent +0.75" ascent -
0.20"
# 3 July 2009 PGW changed battpos to 0.0" to make profiles more symmetric

<start:b_arg>

    b_arg: start_when(enum)                2    # pitch idle (see doco below)
    b_arg: num_half_cycles_to_do(nodim)    10    # Number of dive/climbs to performed
                                           # <0 is infinite, i.e. never finishes
    b_arg: end_action(enum)                2    # 0-quit, 2 resume

# arguments for dive_to

    b_arg: d_target_depth(m)               100   #
    b_arg: d_target_altitude(m)            40    #-1 disables
    b_arg: d_use_pitch(enum)               3      # 1 battpos, 2 pitch set once, 3 servo
                                           #      in      rad      rad
    b_arg: d_pitch_value(X)                -0.489 # (-0.384 -0.454 -0.524 rads = -22 -26
-30 degrees)
#    b_arg: d_pitch_value(X)                +0.75 # inch
    b_arg: d_bpump_value(X)                -250.0
    b_arg: d_stop_when_hover_for(sec)      1200
    b_arg: d_stop_when_stalled_for(sec)    1200

# arguments for climb_to

    b_arg: c_target_depth(m)               20
    b_arg: c_target_altitude(m)            -1
    b_arg: c_use_pitch(enum)               3      # 1 battpos, 2 pitch set once, 3 servo
                                           #      in      rad
rad
    b_arg: c_pitch_value(X)                0.384 # (0.384 0.454 0.489 0.524 rads = 22 26
28 30 degrees)
#    b_arg: c_pitch_value(X)                0.00 # inch
    b_arg: c_bpump_value(X)                +75.0
    b_arg: c_stop_when_hover_for(sec)      1200
    b_arg: c_stop_when_stalled_for(sec)    1200

<end:b_arg>
```


surfac50.ma

behavior_name=surface

surfac50.ma

15-Jan-07 lmm@noc.soton.ac.uk Initial, cloned from surfac40.ma

<start:b_arg>

```

    # arguments for climb_to
    b_arg: c_use_bpump(enum)          2 # pump absolute
    b_arg: c_bpump_value(X)          1000.0 # max, clips anyway
    b_arg: c_use_pitch(enum)          3 # 1:battpos 2:setonce 3:servo
                                         # in rad
rad, >0 climb
    b_arg: c_pitch_value(X)          0.4528 # 26 deg
    b_arg: gps_wait_time(s) 400      # how long to wait for gps
    b_arg: keystroke_wait_time(s) 300 # how long to wait for control-C

```

<end:b_arg>

Appendix B - Basic Commands

This is a brief list of basic commands. For a more complete list see the Operator's Manual pages 32 - 35.

COMMAND	DESCRIPTION
^C	Takes control of the glider and returns the system to GliderDOS or GliderLAB. Ends mission
^E	Extend surface time by 5 minutes
^R	resume mission
^W	Send device warning reports
^P	Immediately restarts the mission
put c_battposs 0	'put c' means to set the commanded value
get m_battpos	'get m' means to get the current measured value
report ++ m_vacuum	'report ++' send the measured value every time it is sampled
report clearall	Stop reporting
ballast	Put into ballast mode (ONLY in GliderLAB)
put c_air_pump 0	Turns off the air_pump
use (+/-) iridium	Turns on or off a device.
callback 30	Hangs up the iridium connection with an instruction to reconnect in 30 minutes.
!put c_air_pump 1	The '!' allows you to use GliderDOS commands whilst in the mission.
logging on/off	Starts recording CTD and glider data in a file.
put c_science_all_on 4	Turns on the CTD to record every 4 seconds
wiggle on/off	Moves all devices back and forth, on or off in order to check hardware
lab_mode on/off	Switches from GliderDOS to GliderLAB and back
use?	Lists sensor in use
where	List GPS position
why?	Lists the reason(s) for an abort
exit (reset)	Powers down the glider – do NOT use at sea!

Table B.1 *A list of the most basic commands for the glider.*

Appendix C - De-gassing the Buoyancy Engine

David White

The prototype Webb box was used to de-gas the oil in the deep engines on the NOCS Slocum electric gliders (Figures C.1 and C.2). It connects to the nose section of the glider, once removed, via the circular connector. There are also two tubes, unlabelled but one nominally called “glider” and the other “cylinder”. A vacuum pump can be switched between them by the left hand valve and a (air) pressure pump via the right hand valve. The two pumps are controlled by a change-over switch. There is a large cylinder with a spigot on the top and an inlet at the base. It is anticipated that the finished product will be more intuitive to operate. There are also two LEDs and a push switch to rotate the valve and indicate its position.

The steps are as follows:

Step	Method
Remove oil from bladder	<ol style="list-style-type: none"> 1. Push the switch to rotate the valve into the open position, i.e. when both LEDs are out. 2. Attach the “glider” tube to the air pump spigot on the glider’s cylinder (fig C.2) 3. Turn the left hand valve to “glider” and select the vacuum pump to switch it on. 4. Oil will now flow from the bladder to the cylinder: continue until it is all in the cylinder (Figure D.4) . 5. Close the valve (L.H. LED on is the “correct” position but any other than “both off” will do). Future versions may automate this procedure. 6. Switch off the vacuum pump and close the left hand valve on the box.
Move the oil from the internal cylinder to the external cylinder (using the Webb box only)	<ol style="list-style-type: none"> 1. Remove the plug from the filling port and connect the external cylinder. 2. Connect the “cylinder” tube to the top of the external cylinder. 3. Open the valve on the external tube inlet 4. Turn the “vacuum” switch to “cylinder” and the pump switch to “glider” 5. Select “vacuum pump” to start the pump. (Future versions may allow simultaneous operation of both pumps.) 6. Oil will now flow into the cylinder (it will start as soon as the valves open, before the pump starts). 7. Rotate and tilt the nose section to help the air to come out of the bellows inside the glider’s cylinder. 8. Continue until the oil level no longer rises and it ceases to bubble. Let any froth die down if it is in danger of entering the vacuum pump line. 9. Close the external cylinder inlet valve and continue to evacuate to remove as much air as possible. 10. Stop the pump.

Move the oil from the internal cylinder to the external cylinder using an external vacuum pump (the vehicle evacuating pump)	<ol style="list-style-type: none"> 1. Remove the plug from the filling port and connect the external cylinder. 2. Connect the vacuum pump to the top of the external cylinder using one of the valves provided. 3. Open the valve on the external tube inlet 4. Turn the pump switch to “glider” 5. Select “pressure pump” to start the pump. 6. Start the vacuum pump. 7. Oil will now flow into the cylinder (it will start as soon as the valves open, before the pump starts). 8. Rotate and tilt the nose section to help the air to come out of the bellows inside the glider’s cylinder. 9. Let any froth die down if it is in danger of entering the vacuum pump line. Continue until the oil level no longer rises and it ceases to bubble. 10. If air starts to bubble through in large quantities once the oil has been removed, stop the vacuum pump immediately. Some of the gliders’ oil pumps will allow air to be drawn past the shaft seal, if a strong vacuum is applied. 11. Close the external cylinder inlet valve then restart the vacuum pump to remove as much air as possible. 12. Stop the pump.
Refilling the glider	<ol style="list-style-type: none"> 1. Remove the tube connecting it to the glider and bleed out any air remaining in it, then reconnect. 2. If using the Webb box, turn the pressure switch to “cylinder” and the vacuum pump to “glider”. 3. If using an external vacuum pump, do the same, inserting the “cylinder” tube into the top of the cylinder, or simply insert a valve into the top of the cylinder as a breather valve. 4. Switch the vacuum pump on to transfer the oil back into the glider.
Finish	<ol style="list-style-type: none"> 1. If there was a lot of degassing, or air was drawn in through the shaft seal, or air appears to remain in the bladder, repeat the procedure to remove any remaining air. 2. Replace the pipes and filling port stopper on the glider.



Figure C.1 *The General arrangement*

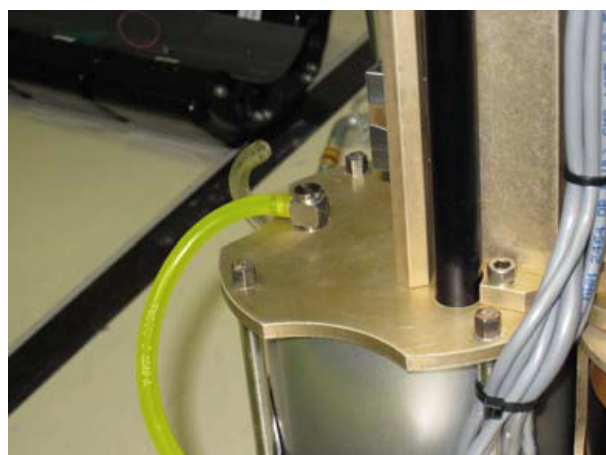


Figure C.2 *Air Pump spigot*



Figure C.3 *The Prototype Webb box*



Figure C.4 *The oil completely removed from the external bladder*



Figure C.5 *Removing oil from the bladder*



Appendix D – Digifin Memo from Webb Research



Potential Digifin re-work:

June 2009

Background:

Recent difficulties with Digifins shipped and in Teledyne Webb Research's production line have revealed issues with the Digifin that can cause the fin to become intermittently or permanently inoperable.

Root cause description:

If the Hall effect sensor was not installed in the proper position there is a chance that the fin will be on the extreme of its calibration and could then move past the mechanical stop. The fin would then stick hard over to port or starboard. This resulted from a board manufacturer not using the spacer guide that TWR had provided, for a batch of boards.

A design review and enhanced testing have revealed the following:

The Hall effect sensor placement from board supplier was not being located to specification. The motor stop is being enhanced (non-critical change). Rudder specs were not being confirmed during modification. Some instances of cracked resistors damaged in board handling have been found. Software was not recognizing this particular failure mode.

To resolve these issues TWR has introduced:

Incoming inspection of the Hall effect sensor placement.

Modification of the design of the motor stop.

Specification confirmation at relevant step processes.

Validation testing including temperature cycling from –10C to 30C, as the fins are operating, as well as standard testing of a full pressure cycle and static test along with a final RF test.

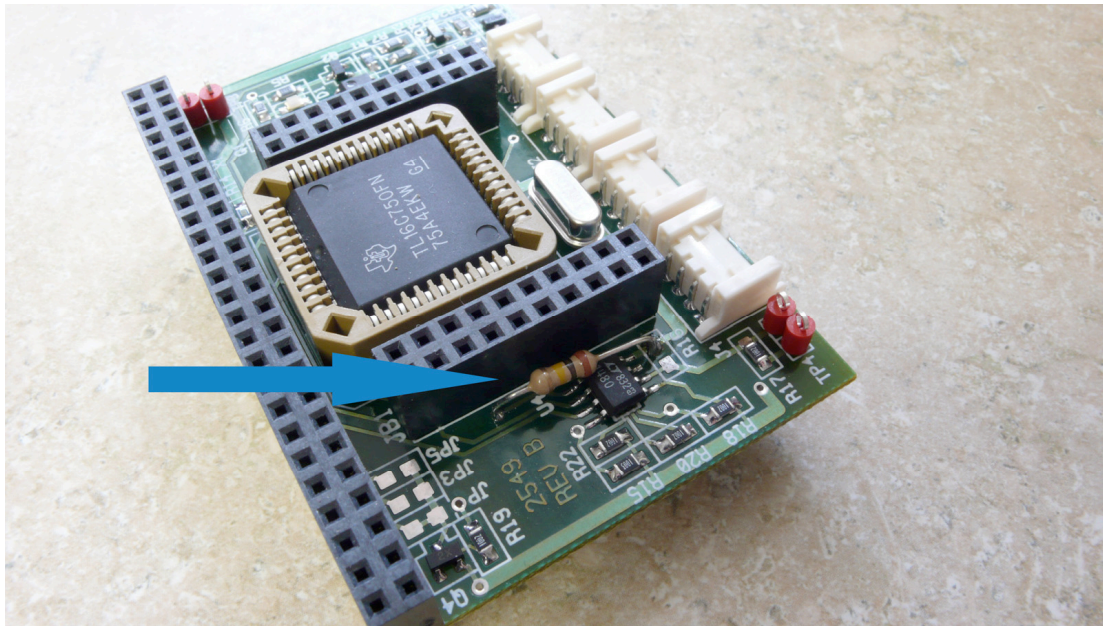
Software enhanced to include fault detection.

While we believe many above issues only affect recently shipped Digifins all Digifin users should perform the following Digifin updates and tests. We apologize for any inconvenience that this may cause and look forward to resolving any faults.

Please do not attempt to open the Digifin.

Digifin checkout Procedure

1. Confirm installation of 100k resistor on 485 bus board located below the CF1 flight Persistor:



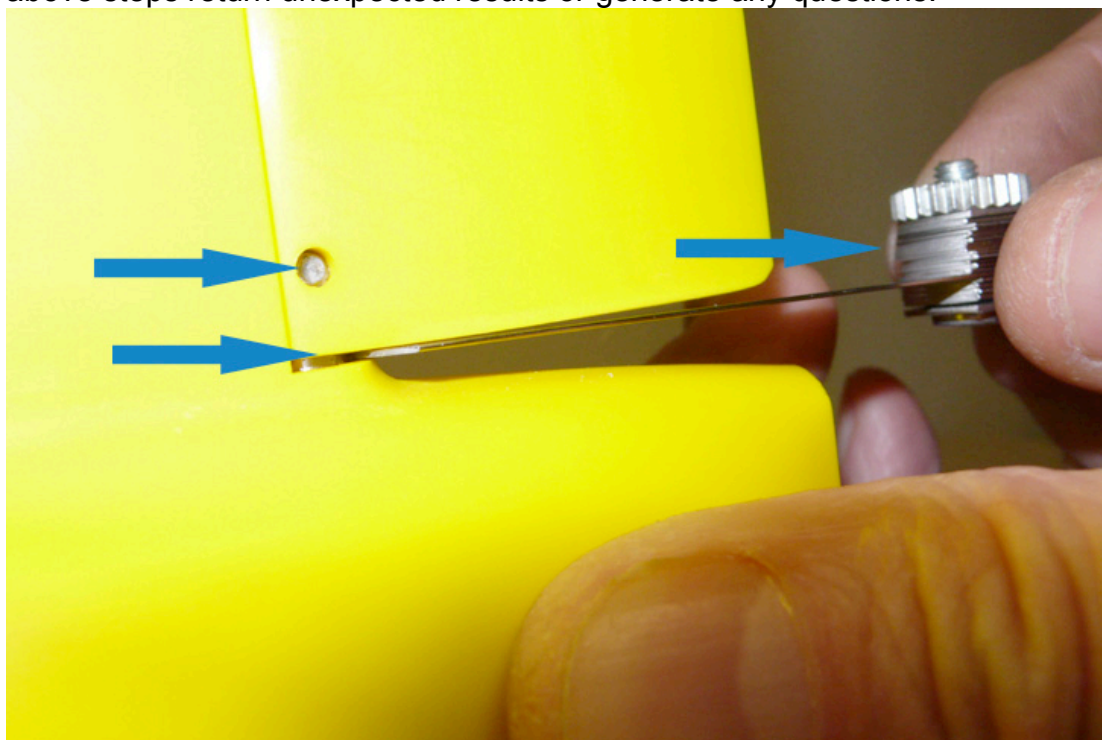
2. Upgrade glider code to 6.36 or current production release:
<ftp://ftp.glider.webbresearch.com/glider/windoze/production/src/doco/software/howto/updating-all-glider-software.txt>
3. From a pico prompt type 'burnhex'. This will update the Digifin firmware.
4. Push the rudder towards the top of the fin and measure gap between bottom of rudder and flat below using a feeler gauge. This distance should be between .010 and .020 inches or .25 and .5 millimeters.
5. Measure the distance between the bottom of the rudder and the centerline of the rudder retaining screw. It should measure .245-.255 inches or 6.22-6.65 mm.
6. From lab mode type the following commands:
digifin rr 106
Result should be less than 220
digifin rr 107
Result should be more than 800

Example

```
GliderLab I-3>digifin rr 106
Register 106 REG_DIGIFIN_STARTUPCAL_PORTSTOP = 140.0000000
GliderLab I-3>digifin rr 107
Register 107 REG_DIGIFIN_STARTUPCAL_STBDSTOP = 873.0000000
GliderLab I-3>
```

7. Observer Digifin motion on glider startup (power cycle). The rudder should move smoothly to both sides twice.
8. Wiggle fin for 15 minutes.

Please contact Glidersupport@Webbresearch.com to proceed if any of the above steps return unexpected results or generate any questions.



Appendix E – Draft Glider Pilot Proforma

Glider	<i>Dynamite</i>	Date	
		Time	GMT/BST
Pilot	PI	David Smeed	
SBD files			

Property	Yes/no/#	Comment/action
General		
Time that glider surfaced		
Time that glider dived		
GPS position		
Is the glider at the expected position?		
Data successfully downloaded?		
Files uploaded if applicable		
Aborts?		
Oddities?		
Battery voltage		
Leak detect?		
Vacuum measurement		
Did the glider time out?		
Hours since previous contact		
Did surfacing time match the predicted time?		
Are the volumes of oil displaced consistent with commanded values?		
Are the measured values spreading – i.e. air in system?		
Is the dive rate stable?		
Is the pitch stable and within limits?		
Are the pitch battery positions as expected?		
Number of yos completed		
Are yos symmetrical?		
Are yos to the correct depth?		
Other comments/notes (attach plots from IGL00 if necessary)		

Appendix F - Thermal Buoyancy Engine

The thermal buoyancy engine developed by Webb Research uses the difference in temperature between the surface and the operating depth to power the glider. As the buoyancy engine is the greatest energy drain in the glider this system has the potential to greatly increase the predicted mission durations. The onboard batteries power the valves, electronics, CTD and communications systems. The thermal engine is very inefficient (~3%) but as the ocean is of a vastly greater mass than the glider this does not present a problem.

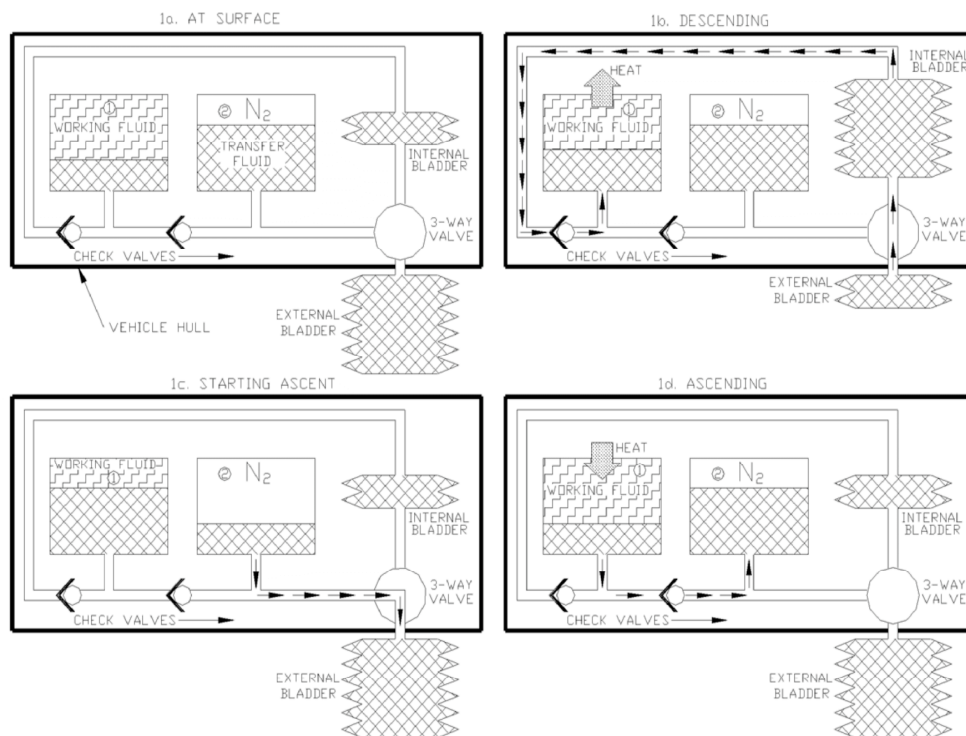


Figure G.1 A schematic of the Slocum Thermal Glider thermodynamic cycle. (taken from Webb 2001)

Operating Principle

There are four holding areas for the fluids involved:

- External bladder, forces the sea water out of the flooded nose cone of the glider for climbing and contracts to allow the sea to enter the nose cone for diving
- The internal bladder or reservoir that the glycol from the external bladder is transferred to on diving.
- The large external piston tubes that contain the working fluid that changes volume with temperature. These are mounted on the underside of the glider to improve the heat exchange and to maximize the volume of wax available.
- The nitrogen pressurized storage chamber for the glycol.

There are three fluids:

- Wax, the working fluid that changes state in the temperature range expected
- Glycol, the buoyancy oil that is used to make the glider dive and climb
- Nitrogen gas, the energy storage medium.

Buoyant state

- The majority of the glycol is in the external bladder. The wax has melted and expanded, thus pressurizing the nitrogen in the storage chamber.

Starting the dive

- The valve between the internal and external bladders is opened. The pressure differential between the outside of the glider and the partial vacuum inside causes the glycol to migrate to the internal bladder. The glider begins to dive to cooler waters.

During the dive

- As the temperature decreases the volume of the wax also decreases, especially during the change of state from liquid to solid. Energy is removed from the system. This decrease in volume draws the glycol from the internal bladder into the piston tubes, thus evacuating the internal bladder.

Starting the ascent

- The external bladder is subject to a large external pressure ($>1000\text{dbar}$). The valve between the pressurized storage chamber and the external bladder is opened. The pressurized nitrogen expands and the glycol is forced from the storage chamber into the external bladder. For this to work the nitrogen must be pressurized a greater amount than the pressure due to the depth. Once the bladder is filled the valve is closed.

During the ascent

- The wax melts and expands as the glider moves into warmer waters. This causes the glycol to move from the piston tubes into the storage chamber and thus re-pressurize the nitrogen. Energy is transferred into the glider. Once on the surface the equilibrium buoyant state has been restored.

Energy Considerations

Surface – Elastic potential energy stored in glider in storage chamber, wax in high-energy state, max PE

Diving – thermal energy in wax transferred from glider to ocean, GPE lost.

Inflexion – elastic potential energy transferred from storage chamber to gain GPE

Climbing – thermal energy transferred into the wax and, thus, storage chamber from ocean, GPE gained.

Appendix H – Energy Consumption Spreadsheets from Webb Research

Electric Glider Mission Spreadsheet		Webb Research Corporation
Mission Parameters Maximum Profile Depth (Meters): 980 Minimum Profile Depth (Meters): 0 Horizontal Velocity (Meters/Sec.): 0.4 Vertical Velocity (Meters/Sec.): 0.13 Profile Parameters: T = Time, N = Profile Number, D = Distance: Number of Profiles before surface: 2 Surface Time (Minutes): 15 Avg. Operating Temperature (C): 13	Calculated Parameters Trajectory Angle (Degrees): 18.0 Profile Duration (Minutes): 251.3 Profile Distance (Meters): 6031 Number of Profiles Between Surfacing: 2.0 Time Between Surfacing (minutes): 502.6 Distance Between Surfacing (km): 12.06 Derated Energy (Joules): 1.28E+07 Calculated Duration (Days): 1.33E+02 Calculated distance (km): 4.46E+03	
Glider Configuration Pump Installed (100, 200, or 1000 Meter): 1000 1 = enabled 0 = disabled Pinger 0 Altimeter 1 Freewave 0 PTT 1		
Battery Configuration Battery Type: A = Alkaline, T= Tadiran, L = Lithium: A Number of C-Cells: 600 End of Life Voltage (VDC): 11.5 Emergency Number of C-Cells: 10		
Science Configuration Downcast Only = 0, Upcast/Downcast = 1 1 = enabled 0 = disabled Seabird CTD 1 UART 1 U4S 0 Persistor 0 SAM 0 BB21SS 0 BB2C 0		

RAPID-WATCH – Report of the trial glider deployments 2008 - 2009

Electric Glider Power Summary

Origination Date: 19/10/04
 Edited by: [Redacted]
 Comments: [Redacted]
 is measured Data
 is calculated data

Energy Configuration										Mission Parameters										Calculated Parameters										Per Surface Period Data										Battery Desating Information										Comments									
Energy Configuration										Mission Parameters										Calculated Parameters										Per Surface Period Data										Battery Desating Information										Comments									
Energy Configuration										Mission Parameters										Calculated Parameters										Per Surface Period Data										Battery Desating Information										Comments									
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Origination Date: 19/11/04
Last Edited: Tim
Comment: is Toms Data
is measured Data
is calculated data

Energy Configuration		Mission Parameters			Calculated Parameters		
Main	Number of Li Packs 0 Number of C-Cells 600 Stored Energy (Joules) 1.8E+07 Number of C-Cells 1 Number of Li Packs 0	Profile Depth (Meters Sec) 0 Horizontal Velocity (Meters Sec) 0.4 Vertical Velocity (Meters Sec) 1.8E-07 # of Profiles before Surface 0 Surface Time (Minutes) 1	Altitude (Meters) 980 Profile Duration (Minutes) 0.13 Profile Depth (Meters) 0.01 Profile Energy (Joules) 2.0E+07 Calculated Duration (Days) 1.33E+03 Calculated Distance (km) 4.4E+03	Trajectory Angle (Degrees) 18.0 Profile Duration (Minutes) 251.3 Profile Depth (Meters) 6001 Profile Energy (Joules) 1.28E+07 Calculated Duration (Days) 1.33E+03 Calculated Distance (km) 4.4E+03			
Emergency	Number of Li Packs 0 Number of C-Cells 600 Stored Energy (Joules) 1.8E+07 Number of C-Cells 1 Number of Li Packs 0	Profile Depth (Meters Sec) 0 Horizontal Velocity (Meters Sec) 0.4 Vertical Velocity (Meters Sec) 1.8E-07 # of Profiles before Surface 0 Surface Time (Minutes) 1	Altitude (Meters) 980 Profile Duration (Minutes) 0.13 Profile Depth (Meters) 0.01 Profile Energy (Joules) 2.0E+07 Calculated Duration (Days) 1.33E+03 Calculated Distance (km) 4.4E+03	Trajectory Angle (Degrees) 18.0 Profile Duration (Minutes) 251.3 Profile Depth (Meters) 6001 Profile Energy (Joules) 1.28E+07 Calculated Duration (Days) 1.33E+03 Calculated Distance (km) 4.4E+03			

Temp (C)	alkaline	derating factor lithium
0	0.6	0.75
10	0.8	0.87
20	1	1

Level	On V _{avg} (VDC)	On I _{avg} (A)	On P _{avg} (W)	Current at 10 VDC (A)	10 VDC P (W)	Off Current (A)	Off Power (W)	Peak Time (s)	Interval (s)	Switching Time (s)	Interval (s)	On Time (s)	Interval (s)	Total (s)	On Time (s)	Off Time (s)	Per Surface Period Data			Multiplier	Comments	Potential Improvements	
																	On Energy (J)	Off Energy (J)	Energy/Sqr (J/s²)				
1	2.5	2.50E-04	6.25E-04	2.50E-04	0.00E+00	0.00E+00	0.00E+00	4.45E-02	1.51E-04	0.00E+00	6.00E-02	8.00E-02	3.02E-04	2.9%	5.95E-01	0.00E+00	1.70E-04	4.66E-04	5.93E-01	48.21%	1		
2	12	5.30E-01	2.90E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.29E-02	1.51E-04	0.00E+00	6.00E-02	3.02E-04	0.8%	1.95E-04	0.00E+00	1.70E-04	0.8%	1.95E-04	0.00E+00	5.11E-01	45.70%	1	
3	12	5.30E-01	2.90E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.90E-01	1.51E-04	0.00E+00	6.00E-02	3.02E-04	0.0%	5.40E-00	0.00E+00	1.70E-04	0.0%	5.40E-00	0.00E+00	1.70E-04	0.02%	1	
4	12	5.30E-01	2.90E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-01	1.51E-04	0.00E+00	6.00E-02	3.02E-04	0.0%	3.94E-02	4.63E-04	1.70E-04	0.0%	3.94E-02	4.63E-04	1.70E-04	1.14%	1	
5	12	5.30E-01	2.90E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-03	1.51E-04	0.00E+00	6.00E-02	3.02E-04	0.0%	1.54E-03	0.00E+00	3.97E-02	0.0%	1.54E-03	0.00E+00	3.97E-02	0.00%	1	
6	12	5.30E-01	2.90E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-03	1.51E-04	0.00E+00	6.00E-02	3.02E-04	0.0%	1.54E-03	0.00E+00	3.97E-02	0.0%	1.54E-03	0.00E+00	3.97E-02	0.00%	1	
7	12	5.30E-01	2.90E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-03	1.51E-04	0.00E+00	6.00E-02	3.02E-04	0.0%	1.54E-03	0.00E+00	3.97E-02	0.0%	1.54E-03	0.00E+00	3.97E-02	0.00%	1	
8	12	5.30E-01	2.90E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-03	1.51E-04	0.00E+00	6.00E-02	3.02E-04	0.0%	1.54E-03	0.00E+00	3.97E-02	0.0%	1.54E-03	0.00E+00	3.97E-02	0.00%	1	
9	12	5.30E-01	2.90E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-03	1.51E-04	0.00E+00	6.00E-02	3.02E-04	0.0%	1.54E-03	0.00E+00	3.97E-02	0.0%	1.54E-03	0.00E+00	3.97E-02	0.00%	1	
10	12	5.30E-01	2.90E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-03	1.51E-04	0.00E+00	6.00E-02	3.02E-04	0.0%	1.54E-03	0.00E+00	3.97E-02	0.0%	1.54E-03	0.00E+00	3.97E-02	0.00%	1	
11	12	5.30E-01	2.90E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-03	1.51E-04	0.00E+00	6.00E-02	3.02E-04	0.0%	1.54E-03	0.00E+00	3.97E-02	0.0%	1.54E-03	0.00E+00	3.97E-02	0.00%	1	
12	12	5.30E-01	2.90E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-03	1.51E-04	0.00E+00	6.00E-02	3.02E-04	0.0%	1.54E-03	0.00E+00	3.97E-02	0.0%	1.54E-03	0.00E+00	3.97E-02	0.00%	1	
13	12	5.30E-01	2.90E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-03	1.51E-04	0.00E+00	6.00E-02	3.02E-04	0.0%	1.54E-03	0.00E+00	3.97E-02	0.0%	1.54E-03	0.00E+00	3.97E-02	0.00%	1	
14	12	5.30E-01	2.90E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-03	1.51E-04	0.00E+00	6.00E-02	3.02E-04	0.0%	1.54E-03	0.00E+00	3.97E-02	0.0%	1.54E-03	0.00E+00	3.97E-02	0.00%	1	
15	12	5.30E-01	2.90E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-03	1.51E-04	0.00E+00	6.00E-02	3.02E-04	0.0%	1.54E-03	0.00E+00	3.97E-02	0.0%	1.54E-03	0.00E+00	3.97E-02	0.00%	1	
16	12	5.30E-01	2.90E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-03	1.51E-04	0.00E+00	6.00E-02	3.02E-04	0.0%	1.54E-03	0.00E+00	3.97E-02	0.0%	1.54E-03	0.00E+00	3.97E-02	0.00%	1	
17	12	5.30E-01	2.90E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-03	1.51E-04	0.00E+00	6.00E-02	3.02E-04	0.0%	1.54E-03	0.00E+00	3.97E-02	0.0%	1.54E-03	0.00E+00	3.97E-02	0.00%	1	
18	12	5.30E-01	2.90E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-03	1.51E-04	0.00E+00	6.00E-02	3.02E-04	0.0%	1.54E-03	0.00E+00	3.97E-02	0.0%	1.54E-03	0.00E+00	3.97E-02	0.00%	1	
19	12	5.30E-01	2.90E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-03	1.51E-04	0.00E+00	6.00E-02	3.02E-04	0.0%	1.54E-03	0.00E+00	3.97E-02	0.0%	1.54E-03	0.00E+00	3.97E-02	0.00%	1	
20	12	5.30E-01	2.90E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-03	1.51E-04	0.00E+00	6.00E-02	3.02E-04	0.0%	1.54E-03	0.00E+00	3.97E-02	0.0%	1.54E-03	0.00E+00	3.97E-02	0.00%	1	
21	12	5.30E-01	2.90E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-03	1.51E-04	0.00E+00	6.00E-02	3.02E-04	0.0%	1.54E-03	0.00E+00	3.97E-02	0.0%	1.54E-03	0.00E+00	3.97E-02	0.00%	1	
22	12	5.30E-01	2.90E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-03	1.51E-04	0.00E+00	6.00E-02	3.02E-04	0.0%	1.54E-03	0.00E+00	3.97E-02	0.0%	1.54E-03	0.00E+00	3.97E-02	0.00%	1	
23	12	5.30E-01	2.90E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-03	1.51E-04	0.00E+00	6.00E-02	3.02E-04	0.0%	1.54E-03	0.00E+00	3.97E-02	0.0%	1.54E-03	0.00E+00	3.97E-02	0.00%	1	
24	12	5.30E-01	2.90E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-03	1.51E-04	0.00E+00	6.00E-02	3.02E-04	0.0%	1.54E-03	0.00E+00	3.97E-02	0.0%	1.54E-03	0.00E+00	3.97E-02	0.00%	1	
25	12	5.30E-01	2.90E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-03	1.51E-04	0.00E+00	6.00E-02	3.02E-04	0.0%	1.54E-03	0.00E+00	3.97E-02	0.0%	1.54E-03	0.00E+00	3.97E-02	0.00%	1	
26	12	5.30E-01	2.90E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-03	1.51E-04	0.00E+00	6.00E-02	3.02E-04	0.0%	1.54E-03	0.00E+00	3.97E-02	0.0%	1.54E-03	0.00E+00	3.97E-02	0.00%	1	
27	12	5.30E-01	2.90E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-03	1.51E-04	0.00E+00	6.00E-02	3.02E-04	0.0%	1.54E-03	0.00E+00	3.97E-02	0.0%	1.54E-03	0.00E+00	3.97E-02	0.00%	1	
28	12	5.30E-01	2.90E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-03	1.51E-04	0.00E+00	6.00E-02	3.02E-04	0.0%	1.54E-03	0.00E+00	3.97E-02	0.0%	1.54E-03	0.00E+00	3.97E-02	0.00%	1	
29	12	5.30E-01	2.90E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-03	1.51E-04	0.00E+00	6.00E-02	3.02E-04	0.0%	1.54E-03	0.00E+00	3.97E-02	0.0%	1.54E-03	0.00E+00	3.97E-02	0.00%	1	
30	12	5.30E-01	2.90E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-03	1.51E-04	0.00E+00	6.00E-02	3.02E-04	0.0%	1.54E-03	0.00E+00	3.97E-02	0.0%	1.54E-03	0.00E+00	3.97E-02	0.00%	1	
31	12	5.30E-01	2.90E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-03	1.51E-04	0.00E+00	6.00E-02	3.02E-04	0.0%	1.54E-03	0.00E+00	3.97E-02	0.0%	1.54E-03	0.00E+00	3.97E-02	0.00%	1	
32	12	5.30E-01	2.90E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-03	1.51E-04	0.00E+00	6.00E-02	3.02E-04	0.0%	1.54E-03	0.00E+00	3.97E-02	0.0%	1.54E-03	0.00E+00	3.97E-02	0.00%	1	
33	12	5.30E-01	2.90E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-03	1.51E-04	0.00E+00	6.00E-02	3.02E-04	0.0%	1.54E-03	0.00E+00	3.97E-02	0.0%	1.54E-03	0.00E+00	3.97E-02	0.00%	1	
34	12	5.30E-01	2.90E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-03	1.51E-04	0.00E+00	6.00E-02	3.02E-04	0.0%	1.54E-03	0.00E+00	3.97E-02	0.0%	1.54E-03	0.00E+00	3.97E-02	0.00%	1	
35	12	5.30E-01	2.90E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-03	1.51E-04	0.00E+00	6.00E-02	3.02E-04	0.0%	1.54E-03	0.00E+00	3.97E-02	0.0%	1.54E-03	0.00E+00	3.97E-02	0.00%	1	
36	12	5.30E-01	2.90E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-03	1.51E-04	0.00E+00	6.00E-02	3.02E-04	0.0%	1.54E-03	0.00E+00	3.97E-02	0.0%	1.54E-03	0.00E+00	3.97E-02	0.00%	1	
37	12	5.30E-01	2.90E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-03	1.51E-04	0.00E+00	6.00E-02	3.02E-04	0.0%	1.54E-03	0.00E+00	3.97E-02	0.0%	1.54E-03	0.00E+00	3.97E-02	0.00%	1	
38	12	5.30E-01	2.90E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-03	1.51E-04	0.00E+00	6.00E-02	3.02E-04	0.0%	1.54E-03	0.00E+00	3.97E-02	0.0%	1.54E-03	0.00E+00	3.97E-02	0.00%	1	
39	12	5.30E-01	2.90E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-03	1.51E-04	0.00E+00	6.00E-02	3.02E-04	0.0%	1.54E-03	0.00E+00	3.97E-02	0.0%	1.54E-03	0.00E+00	3.97E-02	0.00%	1	
40	12	5.30E-01	2.90E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-03	1.51E-04	0.00E+00	6.00E-02	3.02E-04	0.0%	1.54E-03	0.00E+00	3.97E-02	0.0%	1.54E-03	0.00E+00	3.97E-02	0.00%	1	
41	12	5.30E-01	2.90E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-03	1.51E-04	0.00E+00	6.00E-02	3.02E-04	0.0%	1.54E-03	0.00E+00	3.97E-02	0.0%	1.54E-03	0.00E+00	3.97E-02	0.00%	1	
42	12	5.30E-01	2.90E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-03	1.51E-04	0.00E+00	6.00E-02	3.02E-04	0.0%	1.54E-03	0.00E+00	3.97E-02	0.0%	1.54E-03	0.00E+00	3.97E-02	0.00%	1	
43	12	5.30E-01	2.90E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-03	1.51E-04	0.00E+00	6.00E-02	3.02E-04	0.0%	1.54E-03	0.00E+00	3.97E-02	0.0%	1.54E-03	0.00E+00	3.97E-02	0.00%	1	
44	12	5.30E-01	2.90E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-03	1.51E-04	0.00E+00	6.00E-02	3.02E-04	0.0%	1.54E-03	0.00E+00	3.97E-02	0.0%	1.54E-03	0.00E+00	3.97E-02	0.00%	1	
45	12	5.30E-01	2.																				

